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(NASA-TM-73507-Vol-1) EFFECT OF AIR
TEMPERATURE AND RELATIVE HUMIDITY AT VARIOUS
FUEL-AIR RATIOS ON EXHAUST EMISSIONS ON A
PER-MODE BASIS OF AN AVCO LYCOMING O-320
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O-320 DIAD LIGHT AIRCRAFT ENGINE
VOLUME I - RESULTS AND PLOTTED DATA

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SUMMARY

E-8916-2

A carbureted four-cylinder air-cooled O-320 DIAD Lycoming aircraft engine was tested to establish the effects of ambient air temperature and relative humidity at various fuel-air ratios on exhaust emissions on a per-mode basis (idle, taxi, takeoff, climb, and approach). The test conditions included carburetor leanout for each of the five modes, air temperatures of 50, 59, 80 and 100°F and relative humidities of 0, 30, 60, and 80%. Combinations of these parameters resulted in over 800 different test conditions.

Fuel-air ratio (calculated on the dry basis) showed the strongest single influence on CO, HC and NO_x exhaust emissions. The results agree well with known general characteristics of spark ignition piston engines operating over the same range of fuel-air ratio. Ambient conditions influence emissions in two ways. Change in air temperature and/or humidity induces a change in fuel-air ratio due to the variation of air density and displacement of air by water vapor. This results in a dependent change in emissions. In addition, for a constant fuel-air ratio, hot/humid ambient air conditions had a significant further influence on the HC and NO_x emissions due to chemical effects on the combustion process. At a rich fuel-air ratio and higher air temperature and relative humidity, the HC emissions increased by as much as 130% in the lower power modes and the NO_x emissions decreased by as much as 90% in the higher power modes; whereas the CO emissions were essentially independent of ambient conditions. For any fixed fuel-air ratio and zero humidity, higher air temperature had virtually no effect on CO, HC and NO_x emissions in any of the test modes, except for the 20% increase in CO emissions in climb.

The report is presented in two volumes. Volume I (herein) contains the results, plotted data, and microfiche film of the data taken at each of the individual test points. Volume II contains a compilation of the data taken at each of the individual test points. Volume II is included on microfilm at the back of this volume.

INTRODUCTION

NASA is involved in a research and technology program aimed at improving general aviation engines. One major objective of the program is to establish and demonstrate the technology which will safely reduce general-aviation piston-engine exhaust emissions to levels consistent with the EPA 1979 emissions standards.

One element of the above program was a joint FAA/NASA General Aviation Piston Engine Emissions Reduction effort. Funded studies have been completed by the two primary engine firms building general aviation piston engines: Avco-Lycoming and Teledyne-Continental. Each contractor tested five different engine models to experimentally characterize emissions and to determine the effects of variation in fuel-air ratio and spark timing on emissions levels and other operating characteristics such as cooling, misfiring, roughness, power, acceleration, etc. The FAA used its NAFEC facility to perform independent checks on each of the engines the contractors tested. It was recognized early in the program that the tests would be conducted under essentially uncontrolled induction air conditions at widely different geographical locations and that a better understanding of temperature and humidity effects would enhance the ability to make a correlation and better comparison of these data. It was also recognized that such understanding would be extremely useful in future emissions compliance testing. Therefore, NASA-Lewis Research Center has undertaken a series of aircraft engine tests to develop such a correlation. Two engines, models identical to ones in the FAA/NASA program, were selected for testing. The engines were: (1) Lycoming model O-320 DIAD 4-cylinder, naturally-aspirated carbureted engine; and (2) a Teledyne Continental Model TSIO-360-C, a 6-cylinder turbocharged, fuel injected engine.

The exhaust emissions for the Lycoming O-320 engine over the EPA emissions test cycle for a range of test conditions were reported in Reference 1. A summary of these baseline cycle test results can be best described by comparing the temperature and humidity results at 100°F and 80 percent humidity with those at 50°F and no humidity, and which shows that with the increased temperature and humidity, CO emissions increased by a factor of 1.6, HC emissions increased by a factor of 2.2, and NO_x emissions decreased by a factor of 3.5. Present-day aircraft engines do not use a temperature-density compensated fuel system. Hence, the cited changes in the exhaust emissions are primarily the result of richer-fuel-air ratios, which occur at the higher air temperatures and humidities.

Ambient conditions can also effect the induction vaporization and basic combustion process, thereby influencing the emissions. Therefore, a series of tests were performed to establish these direct effects for different engine operating conditions (load and fuel/air ratio) and ambient conditions. The results are reported herein. This report is printed in two volumes: Volume I contains the plotted test results and microfiche copies of all of the individual test points. Volume II contains the individual data test points in tabular form.

APPARATUS AND PROCEDURE

Test Facility

The aircraft engine is shown schematically in Figure 1 and photographically on the test stand in Figure 2. The engine was coupled to a 300 hp dynamometer through a fluid coupling in the drive shaft which was located under a safety shield. Engine cooling and induction air were both supplied by a laboratory air distribution system. The cooling and induction air system, as shown in Figure 3, can be controlled to deliver air to the engine over a temperature range of from 50° to 120° F and over a range of relative humidity from 0 to 80 percent. The cooling air was always at the same conditions as the induction air and was directed down over the engine by an air distribution hood. This hood was the same as that which was used by the engine manufacturer in their engine testing. The engine cooling air was removed from the test cell by a high capacity exhaust system which had the inlet located beneath the engine. An additional cell exhaust fan was used to maintain a slightly negative pressure in the test cell. This was done to vent off any combustible or toxic gases which may have been present in the test cell during engine operation.

The engine exhaust was manifolded together in a standard configuration with the emission sample probe located downstream of the manifold. The exhaust was then ducted out of the cell through the roof as shown in Figure 2. Care was taken to insure that the exhaust system was leak-proof. A leak-proof system was necessary to prevent air dilution of the gas sample which would result in erroneous emission measurements.

Engine Description. The 0-320 DIAD is a horizontally opposed, four cylinder, direct drive, air-cooled engine. The engine has a bore of 5.125 inches and a stroke of 3.875 inches with the resulting total piston displacement being 319.8 cubic inches. The compression ratio is 8.50:1. The engine is rated 160 bhp at 2700 rpm and 0.51 BSFC. Fuel metering is performed by a Marvel-Schebler MA4SPA carburetor using grade 100/130 aviation gasoline. A carburetor intake air box was used to insure uniform pressure distribution across the throat. The carburetor was calibrated for full-rich operation at the factory, typical of what might be expected as the rich limit of production engines. The carburetor, at this calibration, constituted the baseline for the engine. The fuel used was standardized reference fuel conforming to the requirements of the ASTM Committee on Aviation Reference Fuels and Certification. Ignition was supplied by a dual Bendix magneto timed to 25° BTDC. The engine is further described in AVCO Lycoming Specification 2283-C (Ref. 2).

Engine Exhaust System. There are two major areas of consideration that can affect the accuracy of emission measurements. These are the leak tightness of the engine exhaust system and the handling of the exhaust gas sample through the gas analyzer.

In order to obtain a representative exhaust gas sample for emissions analysis the individual cylinder exhaust tubes were brought together under the engine to a common header. Allowing for proper mixing, the gas sample probe was located approximately 5 ft.

downstream in the common header. Great care was taken in the design, fabrication and installation of the exhaust system so that it would not leak air into the exhaust gas upstream of the gas sample probe. It was found that the combination of exhaust gas temperature and engine vibration necessitated a number of changes in the exhaust system before an acceptable leak proof system was obtained.

Exhaust Gas Sample Handling. The criteria for exhaust gas analysis were twofold. The sample had to be representative of a complete mixing from all cylinders and the temperature of the gas sample at the analyzer had to be at least 300°F. The sample line from the exhaust gas manifold to the gas analyzer was heated to 300°F using an electrical tape type heater. The Scott analyzer (See Fig. 4) contained the following five analysis meters:

1. Beckman Model 864 Infrared CO Analyzer
2. Beckman Model 864 Infrared CO₂ Analyzer
3. Scott Model 125 Chemiluminescent NO/NO_x Analyzer. The Scott NO/NO_x Analyzer was modified at NASA-Lewis as discussed in reference 3.
4. Scott Model 415 Flame Ionization Detector for HC
5. Scott Model 250 Paramagnetic O₂ Detector.

Careful daily monitoring of these sensitive instruments indicated a need for frequent adjustments. It was necessary to zero and span calibrate these instruments with known gases at least once for each hour of operation. A complete console calibration was carried out at least once a month.

Instrumentation The engine instrumentation and control panel is shown in figure 5. The major measured parameters and estimated system accuracies for this investigation are listed below:

<u>Parameter</u>	<u>Instrumentation</u>	<u>Accuracy</u>
Fuel Flow	Hydraulic Wheatstone Bridge Flow Meter	+ 0.5%
Induction Air Flow	Turbine-type Flow Meter	+ 0.6%
Induction Air Press.	Absolute Transducer	+ 0.50%
Cooling Air Flow	Orifice ΔP Transducer	+ 1.5%
Cooling Air Press.	Absolute Transducer	+ 0.50%
Dew Point	Temp. Controlled Mirrored Photoelectric Sensor	+ 0.7°F
Engine Torque	Shaft Mounted Rotary Transducer Type	+ 0.5%
Dyno. Torque	Load Cell	+ 0.5%
Speed	Magnetic Pickup	+ 0.25%
Exh. Gas Temp.	Chrome-Alumel Thermocouple	+ 0.5%
Cyl. Hd. Temp.	Iron Constantan Thermocouple	+ 0.5%

All instrumentation was connected to the "CADDE" (Central Automatic Digital Data Encoder) Central Data Acquisition System and the data processed on an IBM 360/67 time-sharing computer.

TEST PROCEDURE

The engine leanout tests at various temperatures and relative humidities were conducted for the modes shown below:

<u>Mode</u>	<u>Mode Description</u>	<u>Power Level</u>	<u>Speed</u>	<u>Time in Mode</u>
1	Idle-Out	-----	600	1.0 min.
2	Taxi-Out	-----	1200	11.0 min.
3	Takeoff	(Full Power) 100%	2700	0.3 min.
4	Climb	80%	2430	5.0 min.
5	Approach	40%	2350	6.0 min.
6	Taxi-In	-----	1200	3.0 min.
7	Idle-In	-----	600	1.0 min.

These modes were divided into two distinct test operations. Takeoff, climb, and approach modes were run separately from the idle and taxi modes. In the takeoff, climb, and approach modes, cooling air flow was supplied across the engine at a differential pressure of three inches of water (approximately 2100 CFM). Approach and climb mode tests were run at a constant engine power over the matrix of variables. Takeoff mode tests were conducted at "wide-open throttle" position and consequently the engine power did vary at the various temperature, humidity and fuel-air ratio test conditions. Fuel flow to the engine was varied by adjusting the carburetor mixture control during these three modes.

The idle and taxi modes were conducted with no cooling air flow over the engine. During these two modes, the fuel-air ratio was varied by manually adjusting the "idle mixture screw" on the carburetor. Idle out, taxi out, taxi in, and idle-in were run sequentially at one setting of the carburetor "idle mixture screw". If abnormally rough operation appeared due to prolonged low power operation, the engine speed was increased to 2000 rpm at 150 ft-lbs torque for "clearing".

Emissions data was not recorded, in any of the modes, until the desired temperature and relative humidity was established in the induction and cooling air system and the engine achieved a stabilized operating condition for that mode.

Data Reduction

The LeRC emissions data reduction procedures are as specified by the EPA in the Federal Register (ref. 4). Shown in figure 6 is the flow diagram outlining the data reduction process. Some of the intermediate steps used in the raw emissions data reduction which are not explicitly defined in the Federal Register are summarized below and presented in Appendix A.

Five exhaust products are measured by the emissions analyzer. HC and NO_x are measured on a "wet" basis. The other three, CO, CO₂ and O₂, are measured on a "dry" basis and as a result their

volumetric percentages must be corrected for the water removal. The water correction factor (K_W) used for this conversion is defined as:

$$K_W = 1 - (H_2O)$$

where H_2O represents the total water vapor contained in the products of combustion. The water correction factor is based on a chemical reaction including water vapor, oxygen and carbon balance, measured fuel-air ratio and water-dry air mass ratio. This factor as used was obtained from Teledyne Continental Motors and is included in appendix A.

The Federal Register (ref. 4) states that the total engine exhaust volume flow rate is to be used in the computation of the pollutant emission rate. Appendix A contains the procedure used in obtaining the exhaust volume flow rate. Primarily, it is based on the total intake mass flow rate and the exhaust gas density. The exhaust gas density is calculated from the exhaust molecular weight, air molecular weight and air density at 68°F and 760 mm Hg pressure. The pollutant emission rate and mass per mode is then calculated per the Federal Register (ref. 4).

The time in mode value used in this calculation (lbs/mode emission rate) was stated in the test procedures. The idle out and idle-in emissions were plotted as separate points on the same plots after the calculated emissions values of lbs/mode for both idles were multiplied by a factor of two to normalize them to two minutes. The two minutes represents the total idle time of the emission test cycle. The taxi-out and taxi-in emissions values of lbs/mode for both taxis were normalized to fourteen minutes. The fourteen minutes represents the total taxi time of the emission test cycle. The remaining three modes takeoff, climb, and approach were plotted as calculated (per the Federal Register, ref. 4).

To verify the exhaust gas products concentrations, the Spindt procedure (ref. 5) was used. In this procedure, the fuel-air ratio is based on the measured exhaust gas products. This calculated fuel-air ratio, as presented in appendix A, is then compared to the measured fuel-air ratio. The percent difference between the measured to calculated is defined as:

$$\text{Percent Difference} = \frac{\text{Calculated fuel-air ratio} - \text{Measured fuel-air ratio}}{\text{Measured fuel-air ratio}}$$

DATA AND RESULTS

As mentioned previously, higher air temperature and humidities affect emissions in two ways; (1) indirectly, by increasing the fuel-air ratio, (2) directly, by modifying the combustion process. The tests described herein were performed to establish the latter effort.

The leanout emissions data were taken for the following values of temperature and relative humidity:

Air temperature, °F: 50, 59, 80, 100
Relative humidity, %: 0, 30, 60, 80

Combinations of the above temperatures and humidities at various fuel-air ratios for the five modes tested (idle, taxi, takeoff, climb and approach) resulted in over 800 test conditions.

Comparison of Emissions Data Generated at the Two Extreme Test Conditions

The modal leanout exhaust emissions obtained at the two extreme ambient test conditions (50°F; 0% relative humidity and 100°F, 80% relative humidity) are compared in Figures 7a through 7o.

The CO, HC and NO_x emissions (lb/mode) are shown on the respective figures as solid lines for the 50°F, 0% relative humidity and as broken lines for the 100°F, 80% relative humidity over the various fuel-air ratios tested. At any one fuel-air ratio, the difference in the emissions values between the solid and broken lines represents ambient conditions direct effect on the emissions.

The two extreme ambient test condition effects on CO emissions are shown in figure 7a-e for each of the five engine test modes and various fuel-air ratios. The CO emissions showed some increase at the 100°F, 80% relative humidity condition in all the modes except takeoff. The takeoff mode (fig. 7c) shows a slight decrease in CO emissions. Figure 7f-7j are plots of HC emissions for each of the five test modes. The HC emissions were higher at the 100°F, 80% relative humidity conditions in all the modes except takeoff. The takeoff mode (fig. 7h) shows that the HC emissions were lower at the richer fuel-air ratio and higher in the leaner fuel-air ratio at the 100°F, 80% relative humidity as compared to the 50°F, 0% relative humidity test condition. The emissions in lbs/mode are directly related to the total mass flow through the engine (Appendix A). Therefore the decrease in emissions (CO and HC) in takeoff as temperature and humidity increases is in part attributed to the lower mass flow rate due to the elevated air temperatures at wide open throttle conditions.

The NO_x emissions (fig. 7k-7o) versus fuel-air ratio show a decreased in NO_x emissions at the 100°F, 80% relative humidity for all the modes and all fuel-air ratios tested. This decrease in NO_x emissions was more pronounced at leaner fuel-air ratios.

The data from figures 7a - 7o was used to quantify the variation in emissions (expressed as a % difference) as ambient conditions are changed from cool, dry to hot, moist and is presented as a function of engine operating mode and fuel-air ratio (figs. 8-10). For CO emissions (fig. 8) the climb mode had the largest percent difference with an increase of over 40% occurring at a fuel-air ratio of .07. The only mode showing a decrease in CO emissions was the takeoff mode. It showed a negative percent difference of 16% at a fuel-air ratio of .085.

The percent difference in HC emissions are shown in figure 9. The idle and taxi modes showed increases of over 130 percent difference in HC emissions at rich fuel-air ratios. The percent difference in HC at the approach mode showed the least sensitivity to fuel-air ratio. Again, only the takeoff mode resulted in negative percent differences of HC emissions. This occurred between fuel-air ratio of .080 - .085.

Figure 10 shows that the largest decrease in NO_x emissions as ambient conditions changed from cool, dry to hot, moist was obtained in the climb mode. It showed a fairly constant reduction of about 90% over all the fuel-air ratios tested. The taxi mode was also fairly insensitive to fuel/air reduction ratio. The other modes were strongly effected by fuel/air ratio, and of course, all five modes consistently exhibit negative percent differences.

Effects of Humidity on Modal Emissions at Four Temperatures

For the convenience of those having a further interest in ambient effects on emissions, the following sixty figures contain the emissions test data of over 800 test points. Figures 11 through 14 are divided into four sets by the inlet air temperatures of 50, 59, 80 and 100°F with relative humidities of 0, 30, 60 and 80%. Each set contains fifteen figures lettered "a through o" which show the lbs/mode of CO, HC and NO_x emissions at one temperature and four relative humidities for each of the five engine test mode conditions and at the fuel-air ratios tested.

All of the figures (11 through 14) each contain a list of the reading numbers of the test data plotted. The test data are divided into groups of identical ambient conditions with a symbol to the right of each group. The symbol not only defines the specific ambient test condition but also represents the emission value point plotted on the figure.

The CO emission appeared to be insensitive to humidity at each of the tested temperatures. At the lower air temperature of 50°F and 59°F, relative humidity had essentially no effect on the HC and NO_x emissions. The bulk of the effect of relative humidity on HC and NO_x emissions occur at the higher temperature.

Effects of Air Temperature for Zero Humidity Modal Emissions

To evaluate if temperature alone had any effect on emissions a comparison was made between the (fig. 11 and 14) emissions at 50°F and 100°F air temperature at 0% humidity. Air temperature had little effect on the formation of CO emissions for any given fuel-air ratio in the idle, taxi, takeoff and approach modes. In the climb mode, the test data results showed a constant 20% increase in CO emissions over the fuel-air ratios tested. The effect of air temperature on the formation of HC and NO_x emissions for the five test modes at any of the fuel-air ratios was insignificant.

Comparison of Modal Emissions

The variation in the mode time, exhaust volume flow, and the engine combustion process which occur throughout the EPA cycle, result in substantial differences in the contributions by mode to the total cycle emissions. Mode lean-out curves for the three emissions (CO, HC and NO_x) are graphically shown in figures 15-17 for 59°F air temperature and 60% relative humidity. (The EPA

standard day conditions). Each figure displays one of the emissions expressed in lb/mode versus fuel-air ratio for the five modes of engine operation. From each figure, it is evident that the climb, approach, and taxi modes are the highest contributors of emissions.

Comparison of Constructed Modal Cycle and Baseline Cycle Emissions

The comparison of the cycle emissions constructed from the modal emissions data with the experimental baseline full rich cycle test results (obtained from ref. 1) is shown in figure 18. Modal fuel-air ratio values corresponding to those of the baseline full rich cycle were used in the construction of the cycle emissions over the range of temperatures and humidities. The comparison of the CO emissions resulted in a relatively close agreement with the percent difference ranging from +8 to -13 percent. At the lower three operating temperatures of 50, 59 and 80° F and for all four of the humidities the percent difference between the constructed cycle and baseline cycle HC emissions (obtained from ref. 1) was less than +12 percent. This difference increased up to -24% at the 100° F temperature and 30% relative humidity conditions. The percent difference in NO_x emissions varied from -11 to +63 percent. The largest percent difference occurred at the test condition in which very low NO_x values were generated. Thus, the poor agreement is probably related to computing percent differences of small values having experimental inaccuracies. Overall, however, it was shown that leanout data can be used to construct optimum baseline cycles based on leaner fuel schedules and the data thereby provide a quick and simple method for assessing the benefit of tailored fuel schedules.

CONCLUDING REMARKS

A carbureted four-cylinder air-cooled O-320-DIAD Lycoming aircraft engine was tested to establish the fuel vaporization and combustion effect of air temperature and humidity on exhaust emissions. The test conditions included carburetor leanout at four air temperatures and four values of relative humidity at each temperature for each of the five different engine operating modes. The following conclusions are based on the data obtained and the plots thereof presented in the report.

The general shape of the CO, HC and NO_x emissions vs. fuel-air ratio curves for a given mode is consistent with well known general emission characteristics for spark-ignition piston engines. From these curves, it is apparent that the exhaust emissions are strongly influenced by fuel-air ratio. In addition, hot/humid ambient inlet air conditions which affect the induction vaporization and basic combustion process are seen as significantly influencing the emissions. At a fixed fuel-air ratio with higher air temperatures and relative humidities, the HC emissions increased by as much as 130% and the NO_x emissions decreased by as much as 90% in certain modes.

Lean out curves for each of the emissions illustrated that the climb mode followed by the approach mode were the largest contributors of the CO and NO_x to the EPA cycle emissions, whereas the taxi mode was the largest contributor of the HC emissions. The comparison of the EPA cycle emissions (ref. 1) to the constructed seven mode cycle data resulted in reasonably good agreement. Thus, leanout data from these curves can be used to construct optimum cycle based on leaner fuel schedules and thereby provide a quick and simple method for assessing the benefits of tailored fuel schedules.

The results reported herein are based on tests conducted on one carbureted naturally-aspirated engine. A Continental turbocharged and fuel-injected TSIO-360-C engine has been investigated over the same range of test conditions as the Lycoming engine described herein. A least-squares regression technique of the data from each engine is being planned to study generalized representation of engine emission trends for ambient condition.

APPENDIX A

INTERMEDIATE EQUATIONS USED IN THE RAW

EMISSIONS DATA REDUCTION

The basic computational procedures on emission data reduction are specified in the Federal Register (ref. 4). Presented are only those equations and calculations which are not explicitly defined in the Federal Register.

SYMBOLS

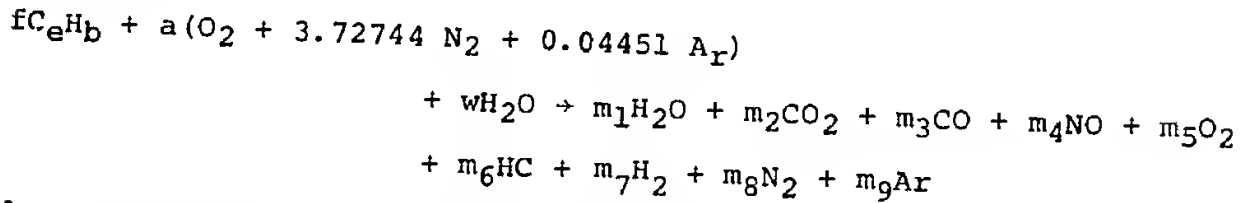
A	air flow, lb/hr
Ar	argon
a	moles of air
$C_e H_b$	molecular formula of the fuel
c	mass fraction of carbon in the fuel
D	density of exhaust products, lb/ft ³
E	exhaust molecular weight, lb/(lb-mole)
F	fuel flow, lb/hr
f	moles of fuel
h	mass fraction of hydrogen in fuel
M	molecular weight of air, 28.96 lb/(lb-mole)
m_n	mole fraction of the compound n
P	equals $(CO) + (CO_2) / [(CO) + (CO_2) + (HC)]$
Q	equals $(O_2) / (CO_2)$
R	equals $(CO) / (CO_2)$
V	exhaust volume flow rate, ft ³ /hr
W	water flow rate, lb/hr
ρ	density of air at 68° F and 760 mm Hg pressure, 0.075 lb/ft ³

Subscripts:

- b number of hydrogen atoms in one molecule of fuel
- d measured on the "dry" basis water removed
- e number of carbon atoms in one molecule of fuel
- n identifies the individual constituent fraction

I. Water Correction Factor

The chemical reaction including water vapor in the air may be written as:



An oxygen balance results in equation (1).

$$m_1 = 2a + w - 2m_2 - m_3 - m_4 - 2m_5 \quad (1)$$

A carbon balance results in equation (2).

$$f = \frac{m_2 + m_3 + m_6}{e} \quad (2)$$

The fuel-air mass ratio may be defined as

$$\frac{F}{A} = \frac{f(12.01 e + 1.008 b)}{a(138.2689)} \quad (3)$$

The water - dry air mass ratio may be defined as

$$\frac{W}{A} = \frac{w(18.016)}{a(138.2689)} \quad (4)$$

Substituting equations (2) to (4) into equation (1) and rearranging

$$m_1 = \left(2.0 + 7.67478 \frac{W}{A}\right) \left[\frac{(m_2 + m_3 + m_6) \left(12.01 + 1.008 \frac{b}{e}\right)}{138.2689 \frac{F}{A}} \right] - 2m_2 - m_3 - m_4 - 2m_5 \quad (5)$$

For clarity equation (5) may be written using chemical symbols to represent the mole fraction for each constituent

$$(H_2O) = \left(2.0 + 7.67478 \frac{W}{A} \right) \left[\frac{(\text{CO}_2) + (\text{CO}) + (\text{HC}) \left(12.01 + 1.008 \frac{b}{e} \right)}{138.2648 \frac{F}{A}} \right] - 2(\text{CO}_2) - (\text{CO}) - (\text{NO}) - 2(\text{O}_2) \quad (6)$$

The above equation (6), represents the total water vapor contained in the products of combustion with each constituent measured on a "wet" basis. Since CO, CO₂, and O₂ are measured dry and since the water correction factor is defined as

$$K_w = 1.0 - (H_2O) \quad (7)$$

equation (6) may be written in terms of dry measurements as

$$\frac{H_2O}{1 - (H_2O)} = \left(2.0 + 7.67478 \frac{W}{A} \right) \times \left\{ \frac{\left[(\text{CO}_2)_d + \frac{(\text{HC})}{1 - (H_2O)} \right] \left[\left(12.01 + 1.008 \frac{b}{e} \right) \right]}{138.2648 \frac{F}{A}} \right\} - 2(\text{CO}_2)_d - (\text{CO})_d - \frac{NO}{1 - (H_2O)} - 2(\text{O}_2)_d \quad (8)$$

The solution to equation (8) for H₂O is an iteration process since HC and NO are measured wet. The water correction factor is then calculated using equation (7).

II. Exhaust Volume Flow Rate

The exhaust volume flow rate can be equated as:

$$V = \frac{A + W + F}{D}$$

The exhaust density can be expressed as

$$D = \frac{PXE}{M}$$

Figure A1 shows the relation between the exhaust molecular weight and F/A ratio obtained from "computer program for calculation of complex chemical equilibrium composition" NASA SP-273 (ref. 6). The pollution production rate is then calculated as specified in the Federal Register (ref. 4).

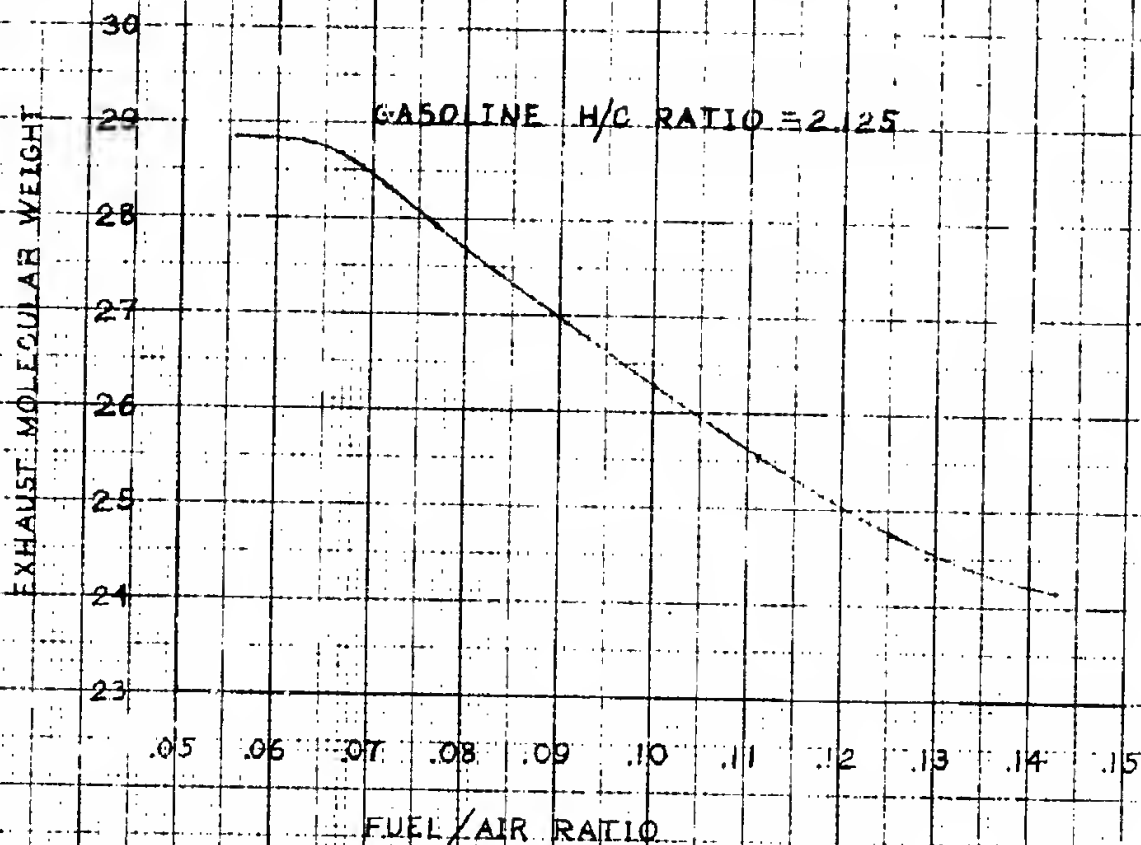


FIGURE A1- EXHAUST MOLECULAR WEIGHT
AS A FUNCTION OF FUEL AIR
RATIO FOR AVIATION GASOLINE

ORIGINAL PAGE IS
OF POOR QUALITY

III. Fuel Air Ratio Based on Exhaust Gas Components
and Procedure of Spindt (ref. 5)

The F/A ratio can be expressed as:

$$\frac{F}{A} = \frac{1}{P \left[11.492 c \left(1.0 + \frac{\frac{R}{2} + Q}{1 + R} \right) + \left(\frac{120h}{3.5 + R} \right) \right]}$$

APPENDIX B

TEST DATA

The data from individual test points, which were taken on a carbureted, four-cylinder, 0-320 DIAD Lycoming light-aircraft engine, have been microfilmed and are contained in the pocket at the back of this volume. These data points represent all of the environmental and engine conditions tested in the individual seven modes in the EPA emissions test cycle as discussed in Volume I. The test data presented herein, representing over 800 data points (readings), were taken at air temperatures of 50°, 59°, 80°, and 100° F at values of 0, 30, 60, and 80 percent relative humidity over a range of fuel-air ratios from 0.06 to 0.113. The data points included in this appendix are all of those for which the exhaust emissions are plotted on a per-mode basis in Volume I of this report. Data point reading number listings are included in tabular form for each series of test conditions and the data symbols which were used for the curves plotted in Volume I. Because of the large number of data points, the data points are arranged numerically by reading number for easy reference.

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6. Gordon, Sanford; and McBride, Bonnie J.: Computer Program for Calculation of Complex Chemical Equilibrium Compositions, Rocket Performance, Incident and Reflected Shocks and Chapman-Jouguet Detonations. NASA SP-273, 1971.

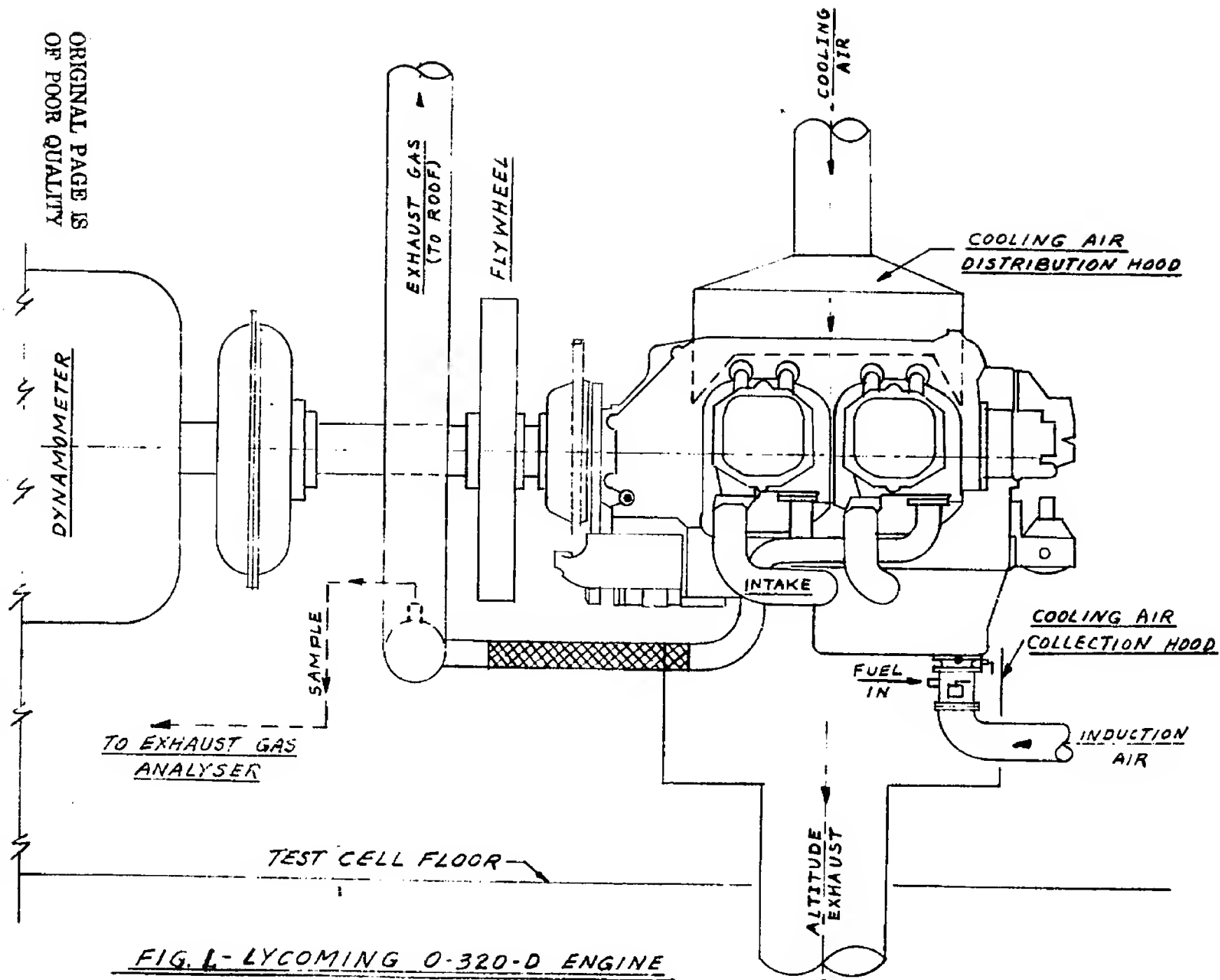


FIG. 1- LYCOMING O-320-D ENGINE

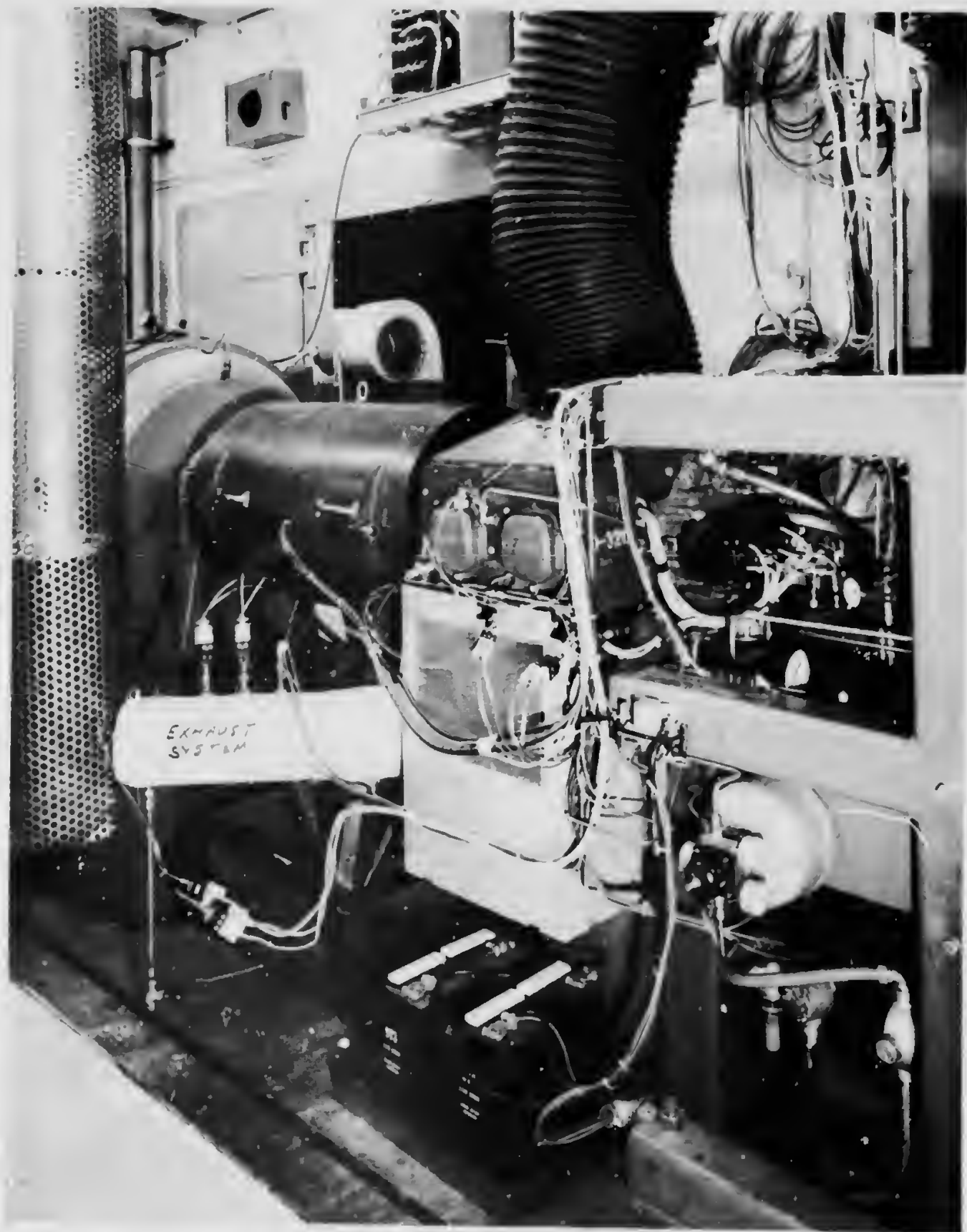


FIGURE 2.

ETC

TEST STAND

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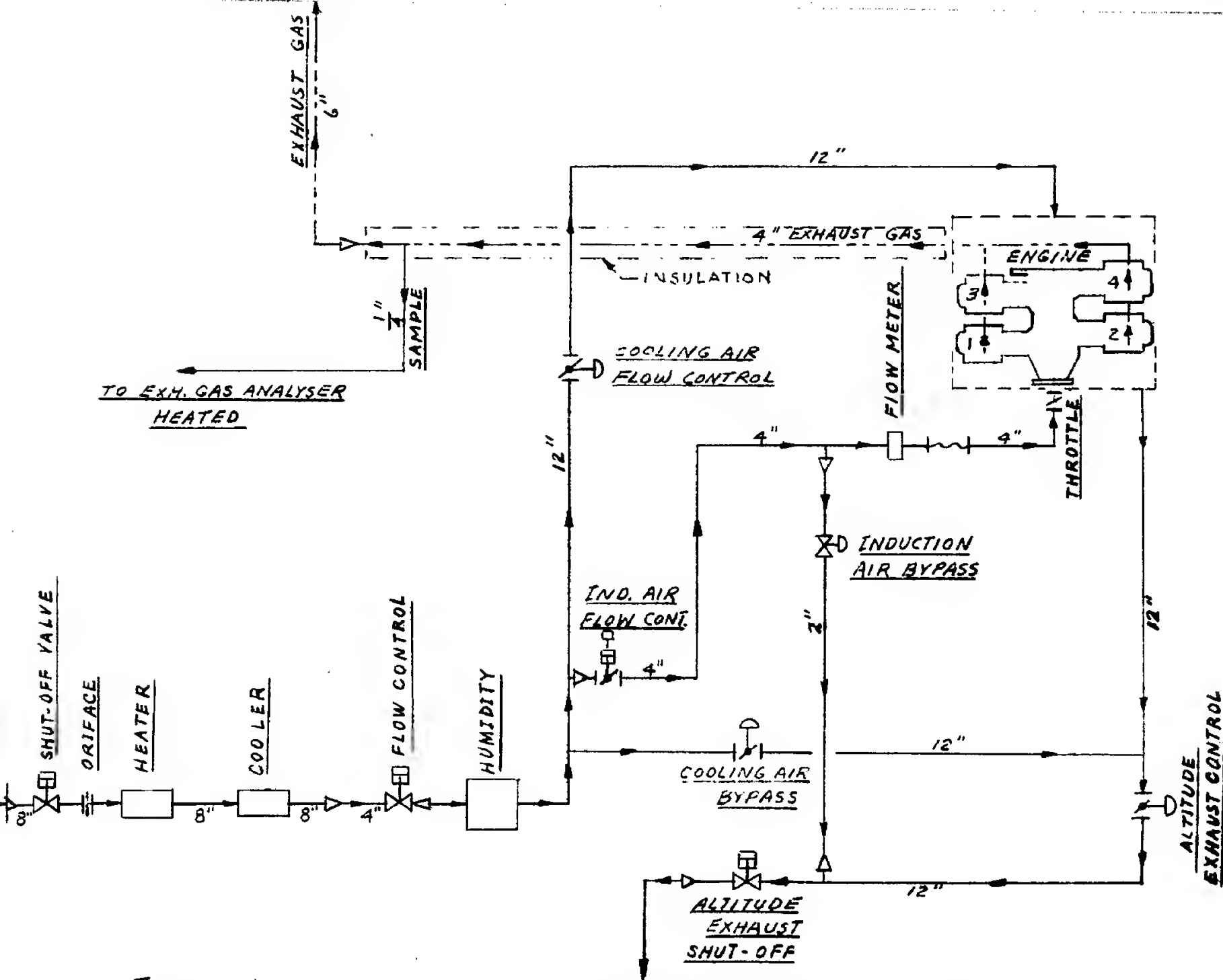
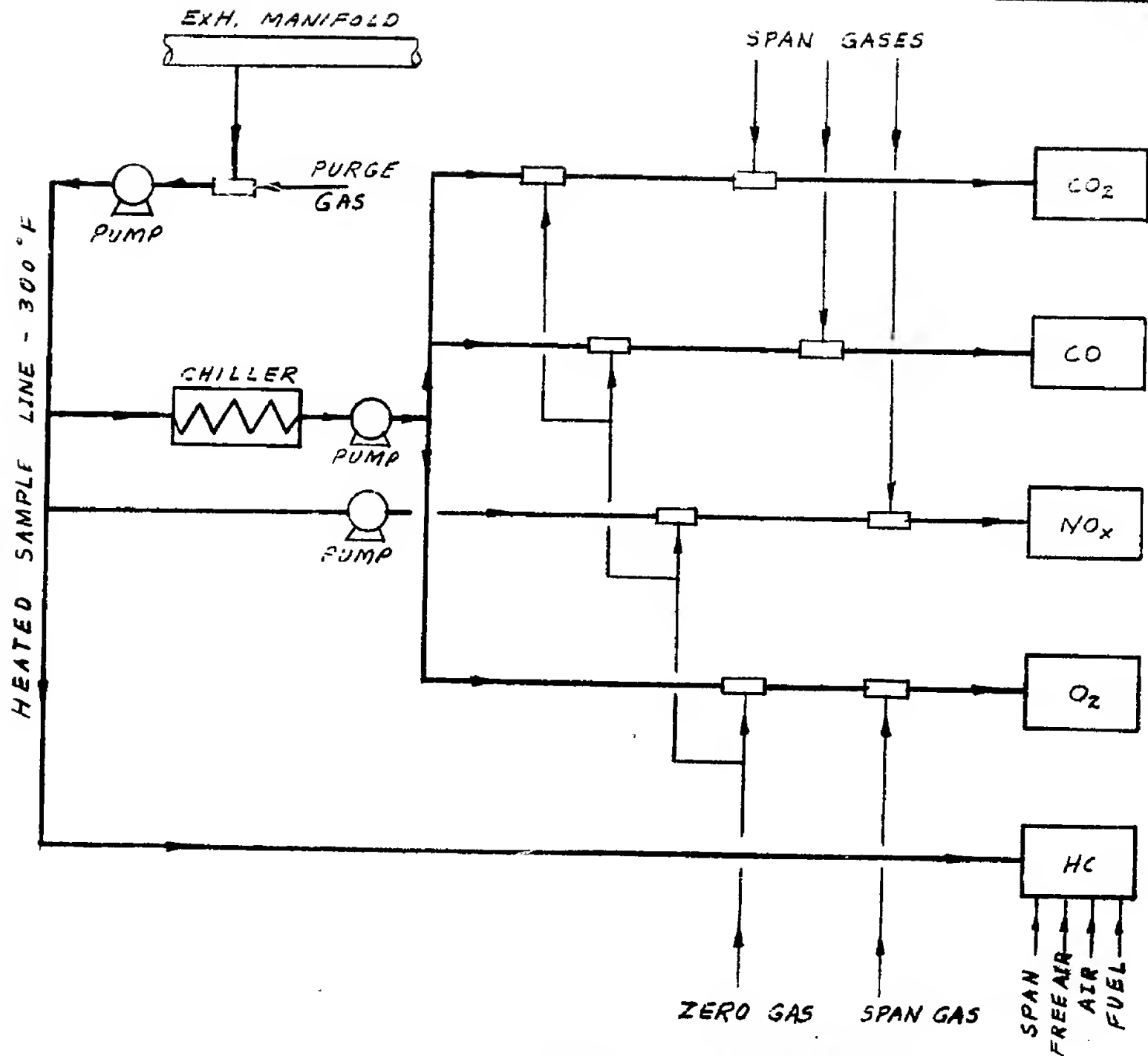


FIGURE 3. ENGINE TEST STAND FACILITY SYSTEMS



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FIG. 4 EXHAUST GAS ANALYZER

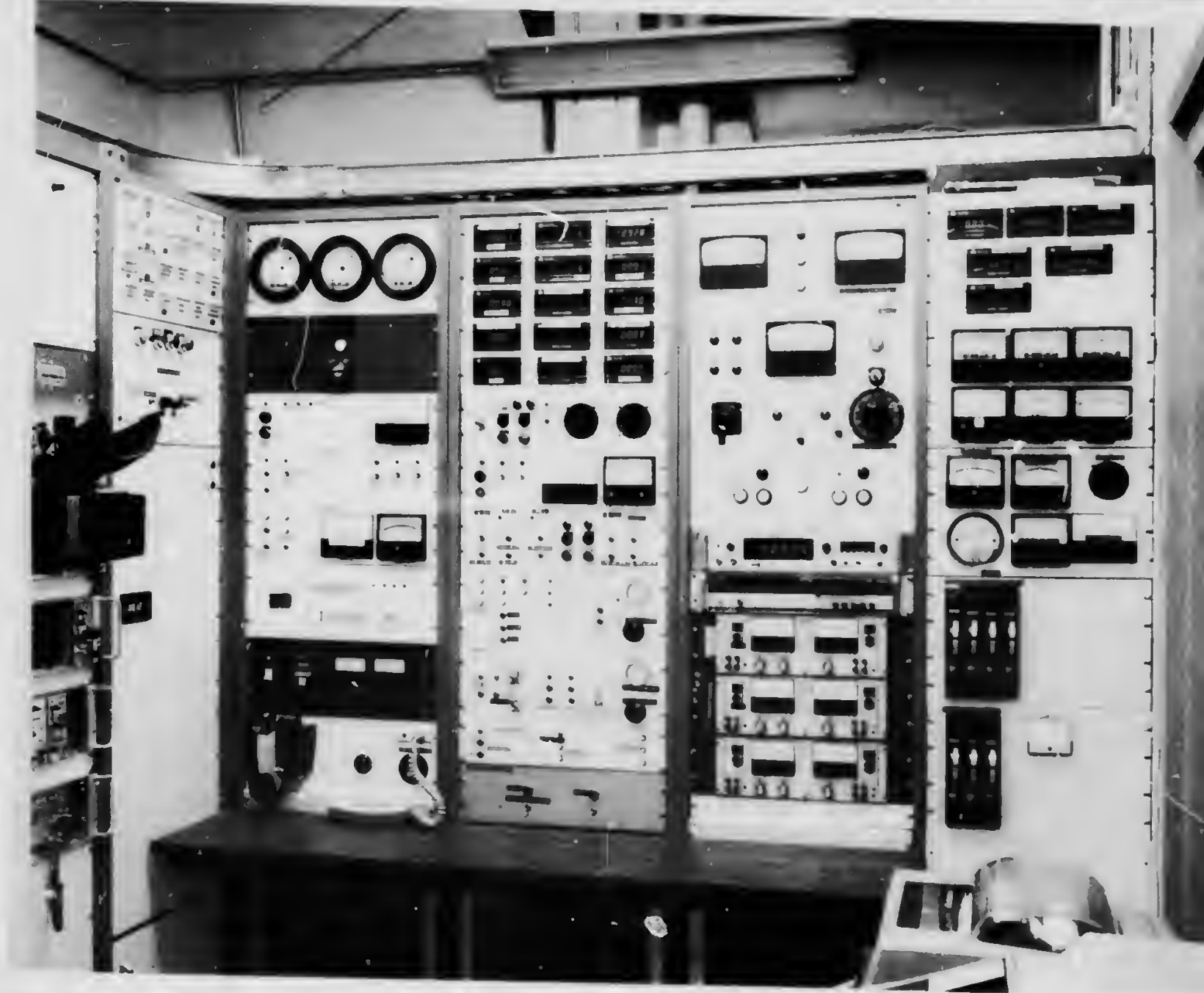
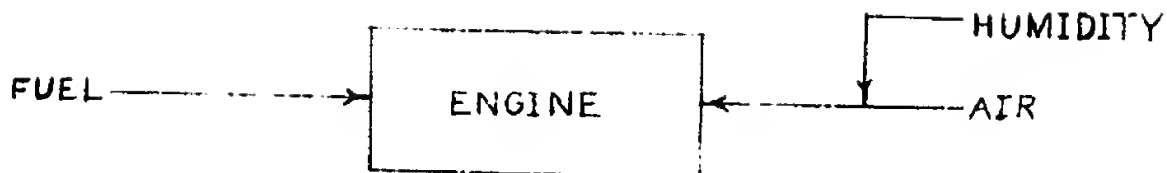
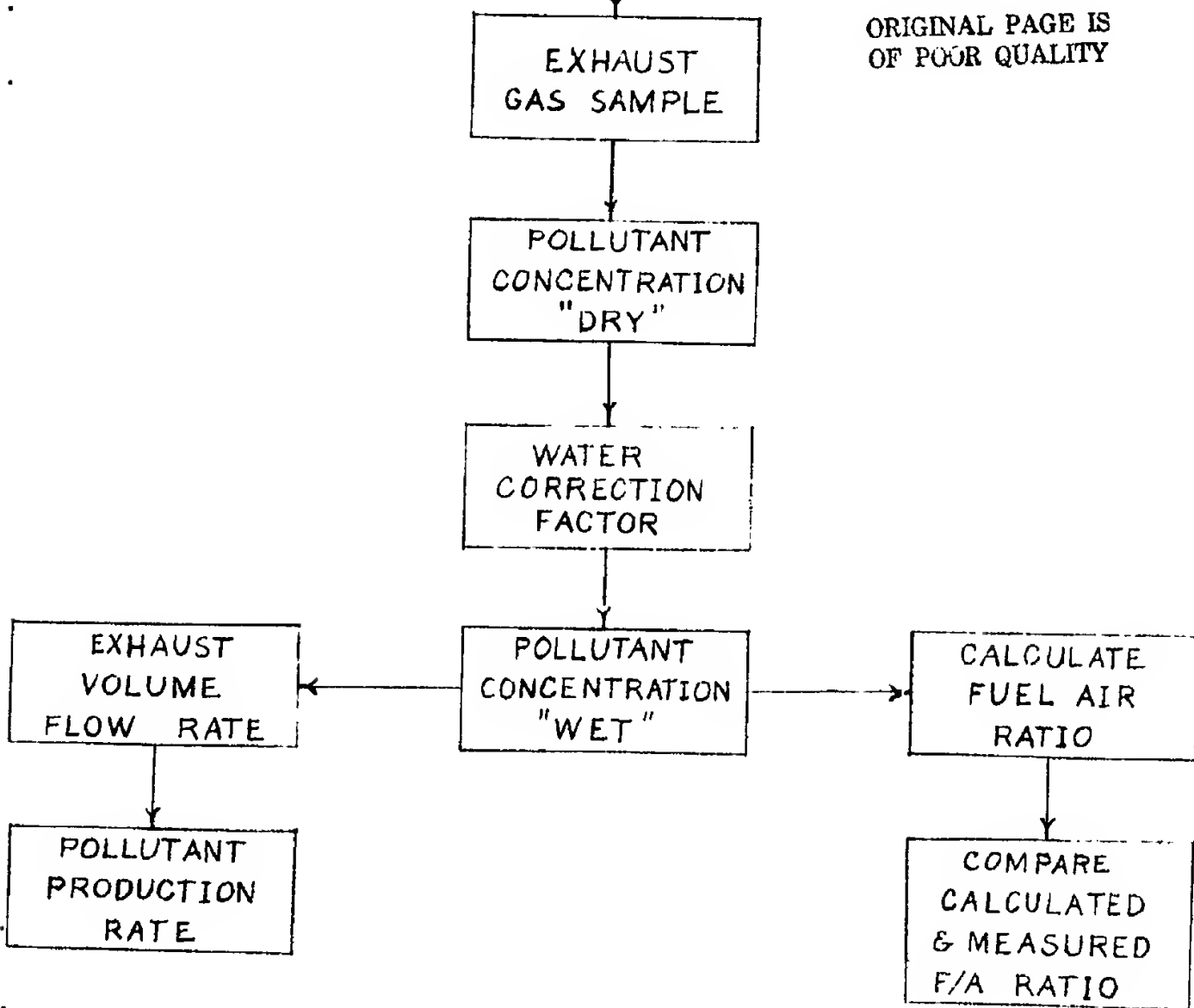


FIGURE 5. ENGINE INSTRUMENTATION AND CONTROL PANEL



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EXHAUST EMISSION
DATA REDUCTION FLOW CHART

FIGURE 6

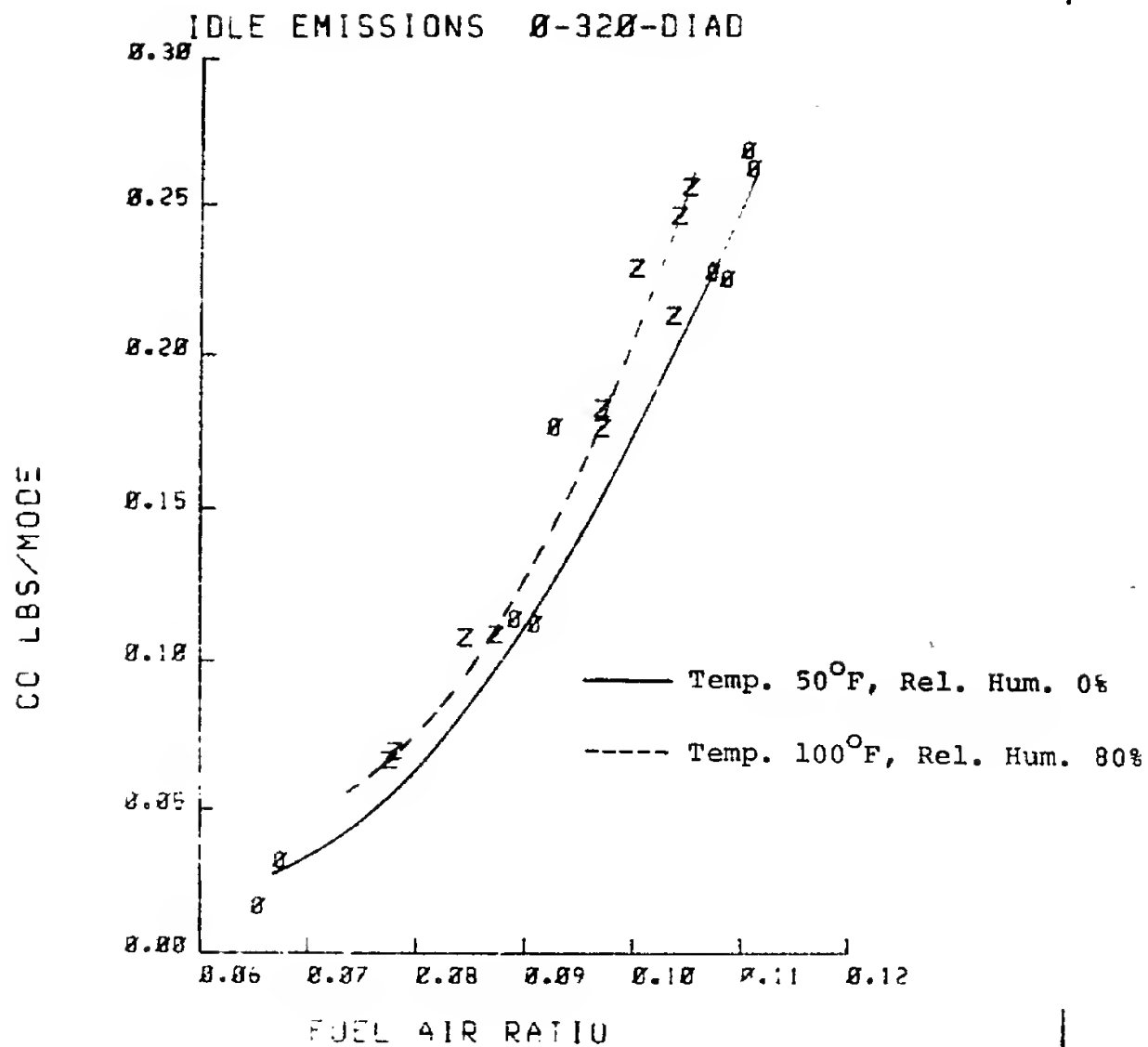


FIGURE 7 a

TAXI EMISSIONS Ø-32Ø-DIAD

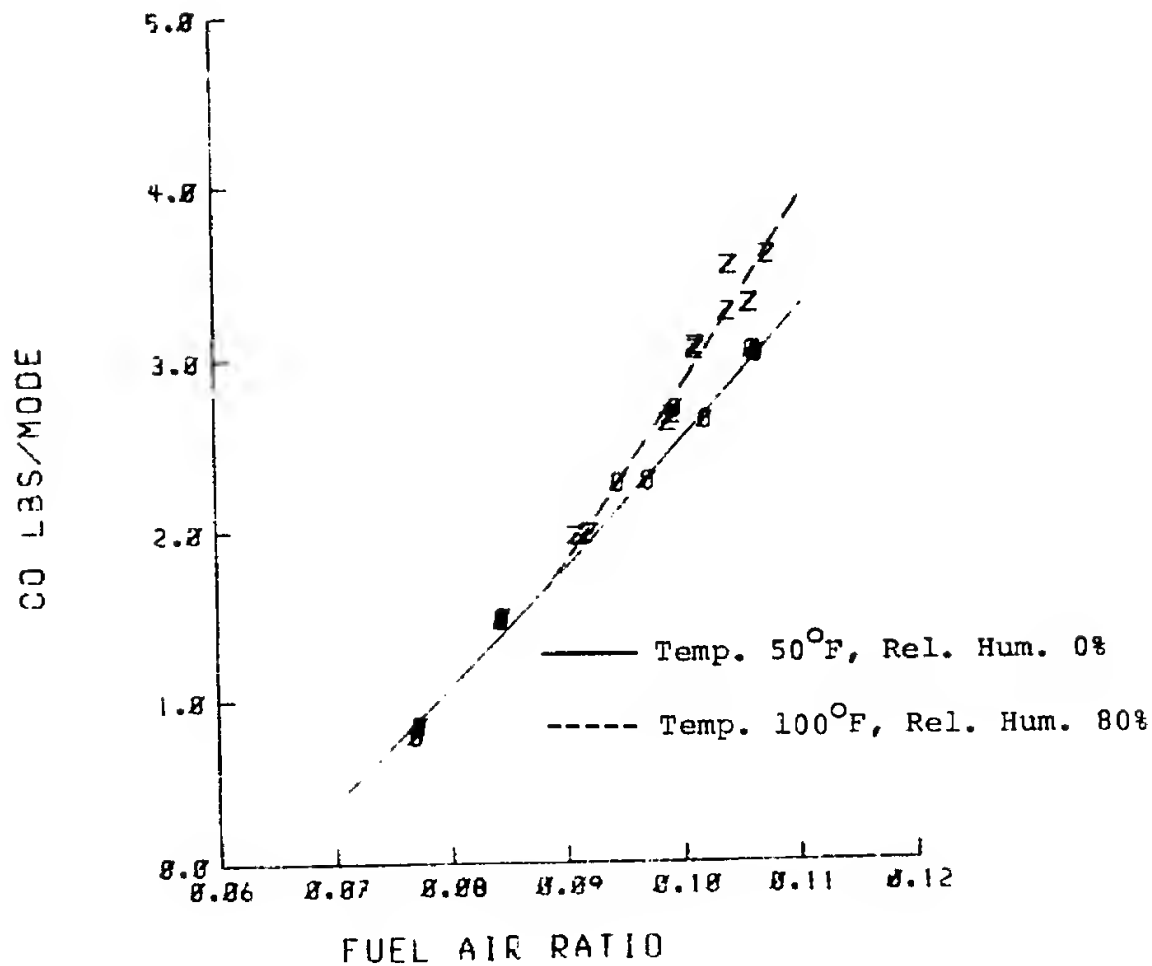


FIGURE 7b

ORIGINAL PAGE IS
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TAKE OFF EMISSIONS Ø-32Ø-DIAD

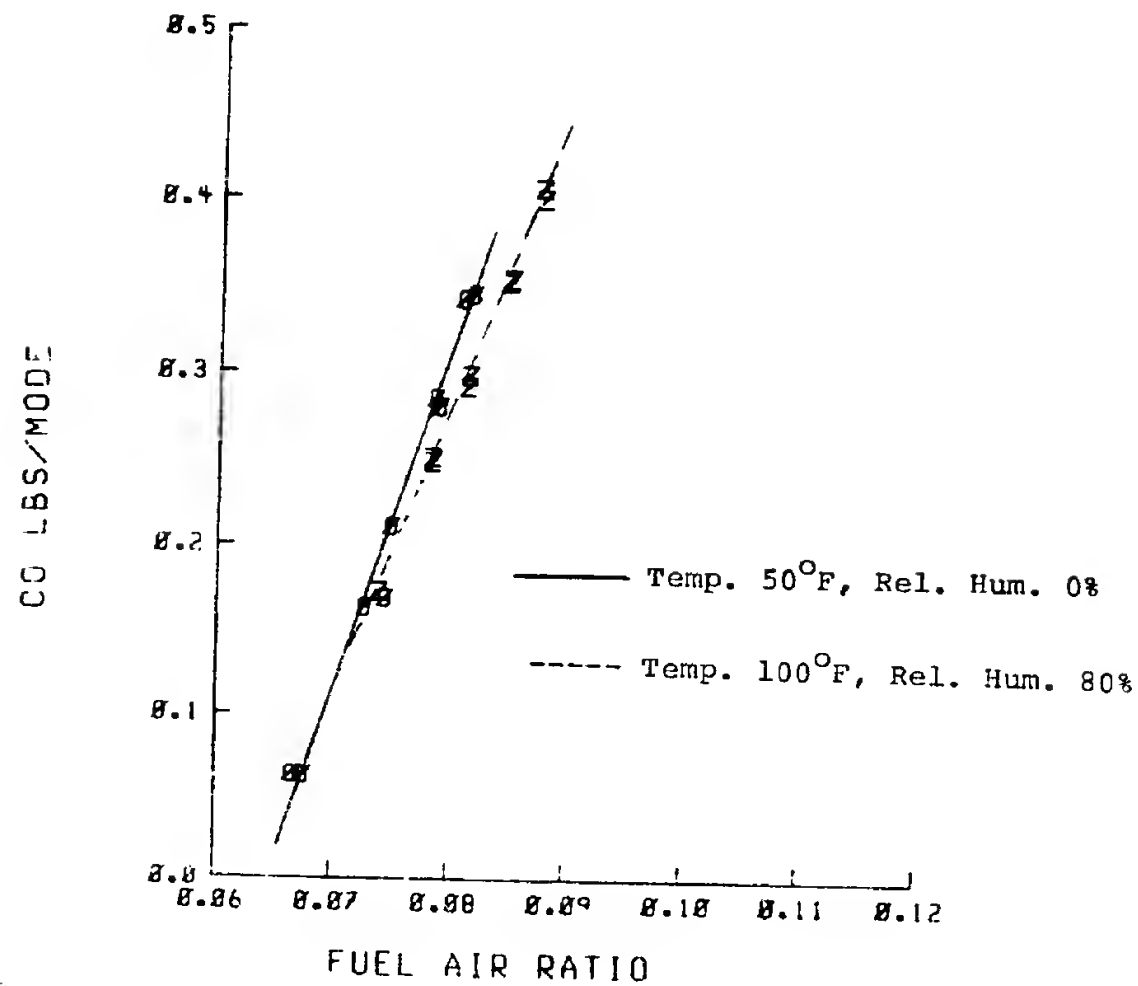


FIGURE 7c

CLIMB EMISSIONS Ø-32Ø-DIAD

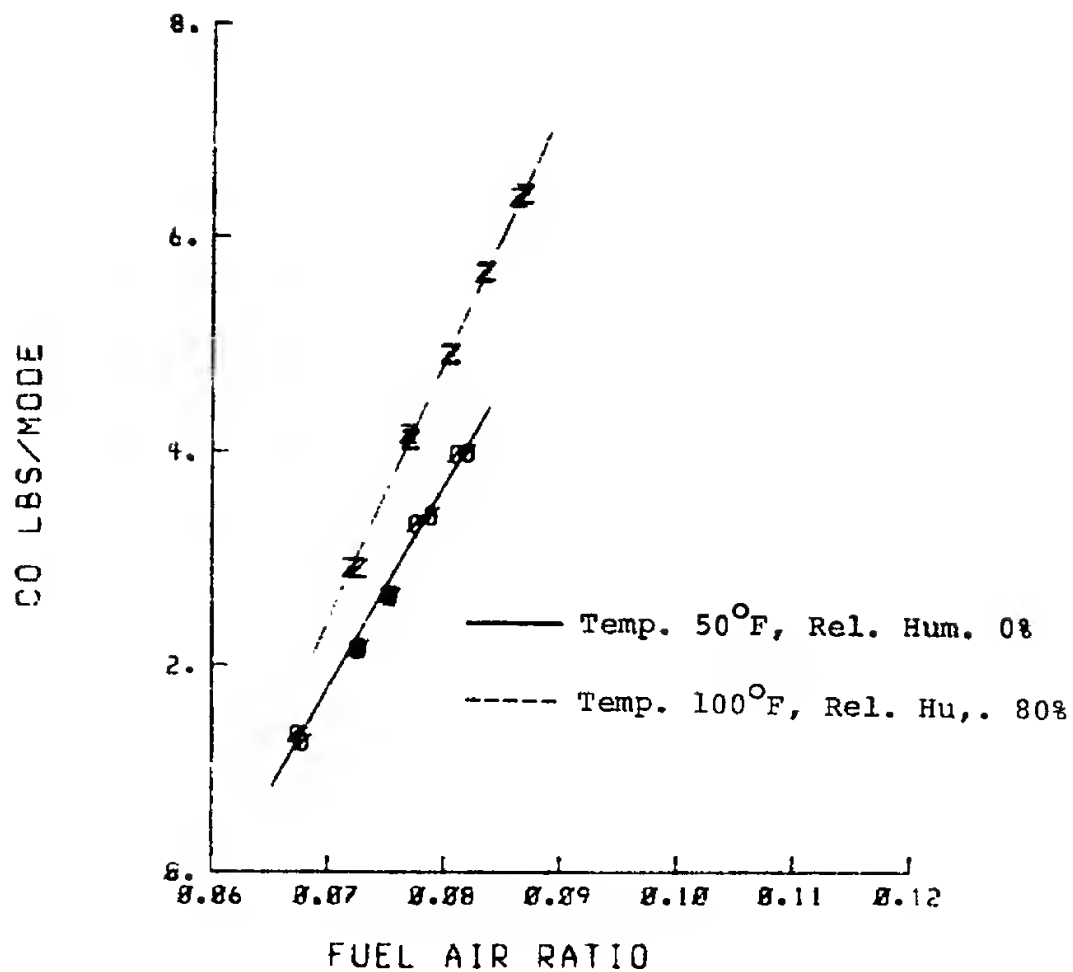


FIGURE 7 a

ORIGINAL FILED IN
OF POOR QUALITY

APPROACH EMISSIONS Ø-32Ø-DIAD

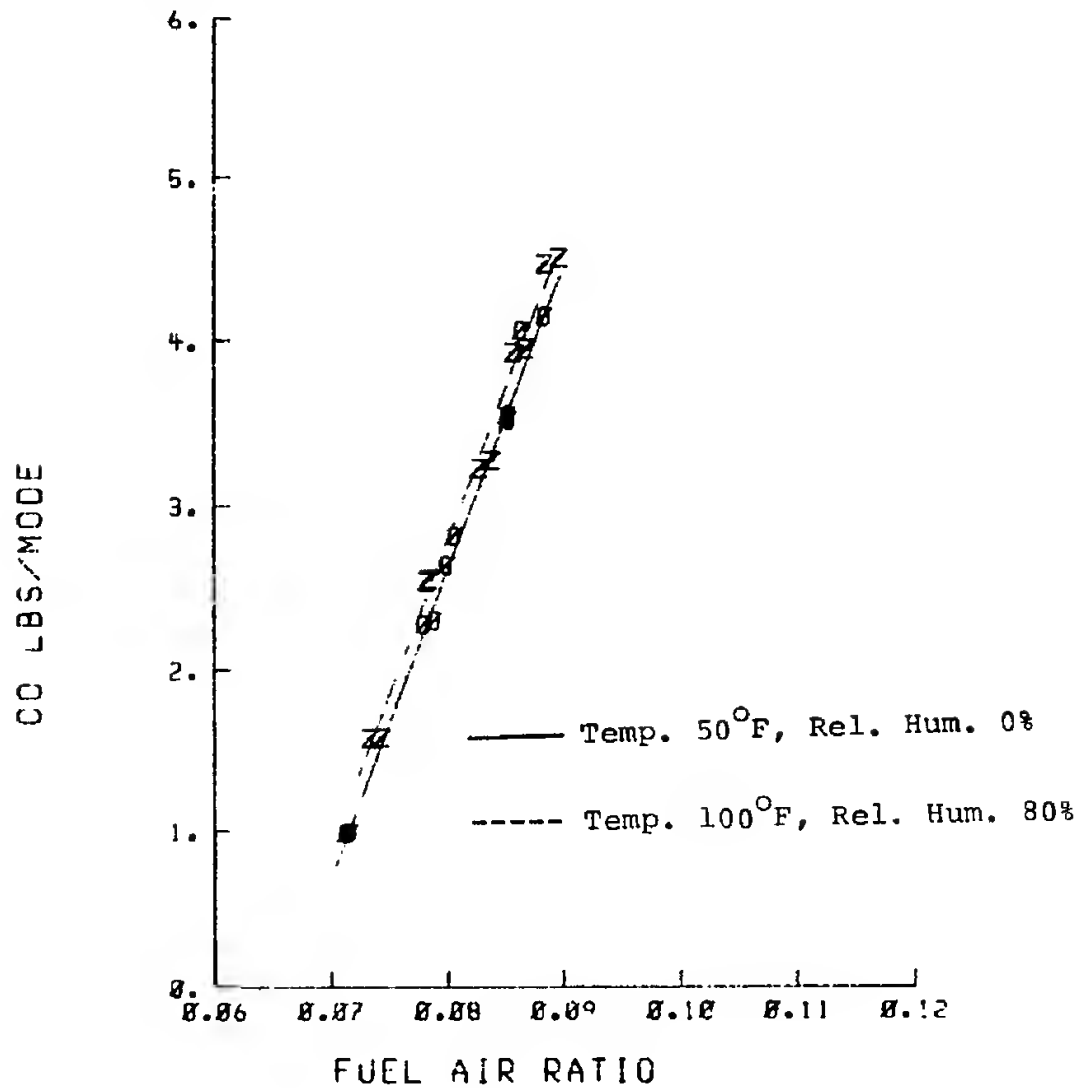
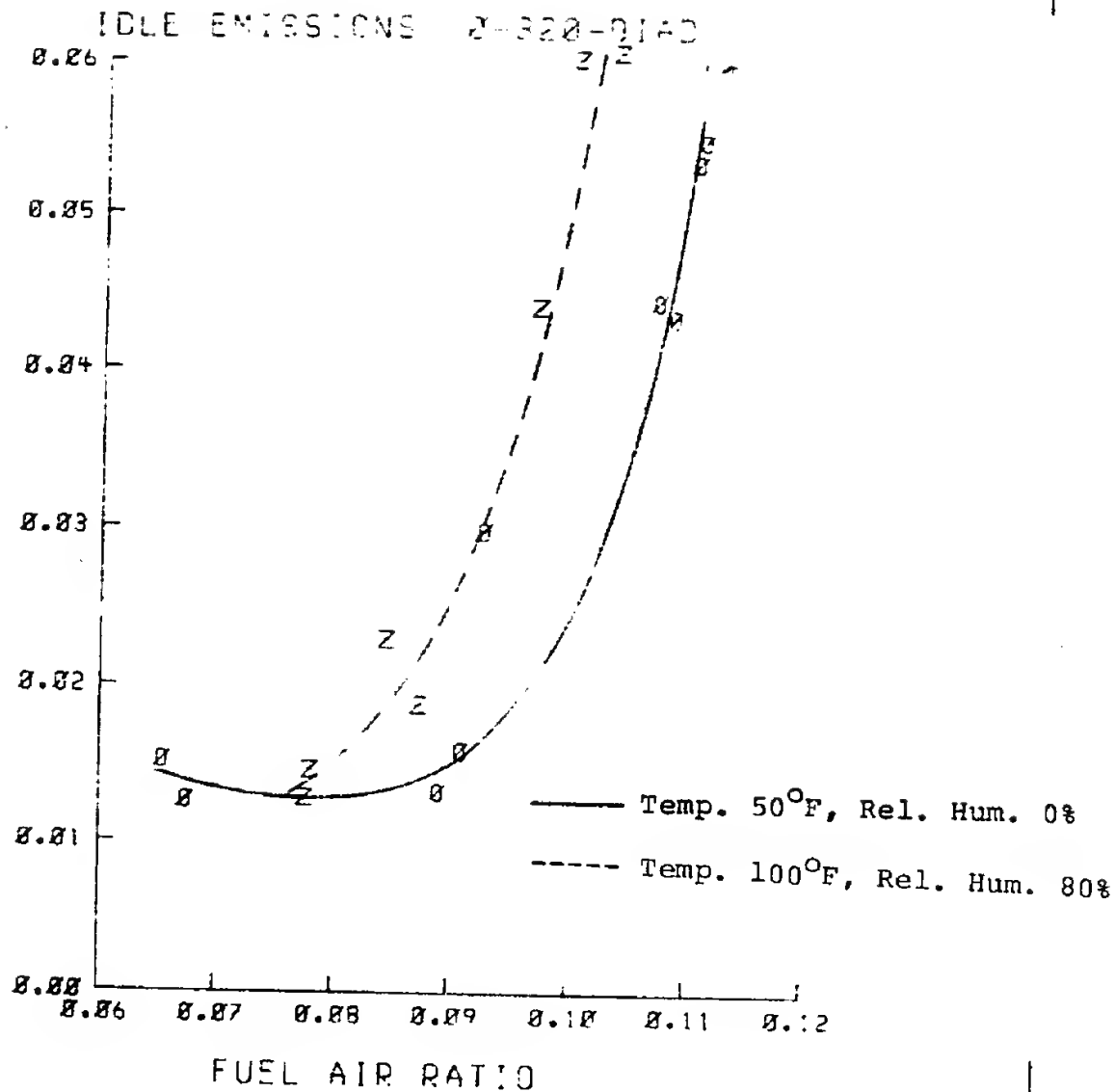


FIGURE 7e

HC LBS/MODE



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OF POOR QUALITY

FIGURE 7f

TAXI EMISSIONS Ø-32Ø-DIAD

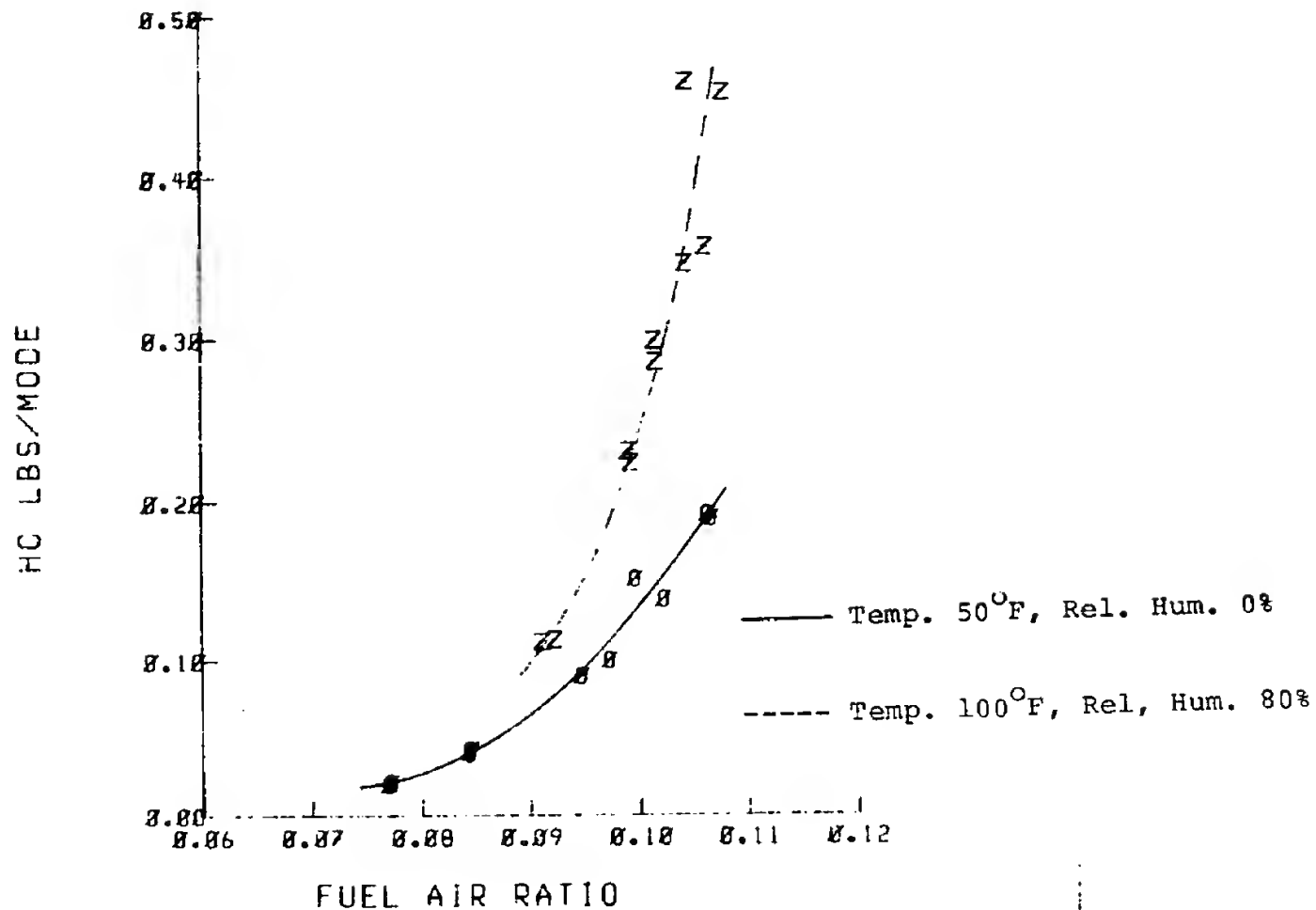


FIGURE 7 g

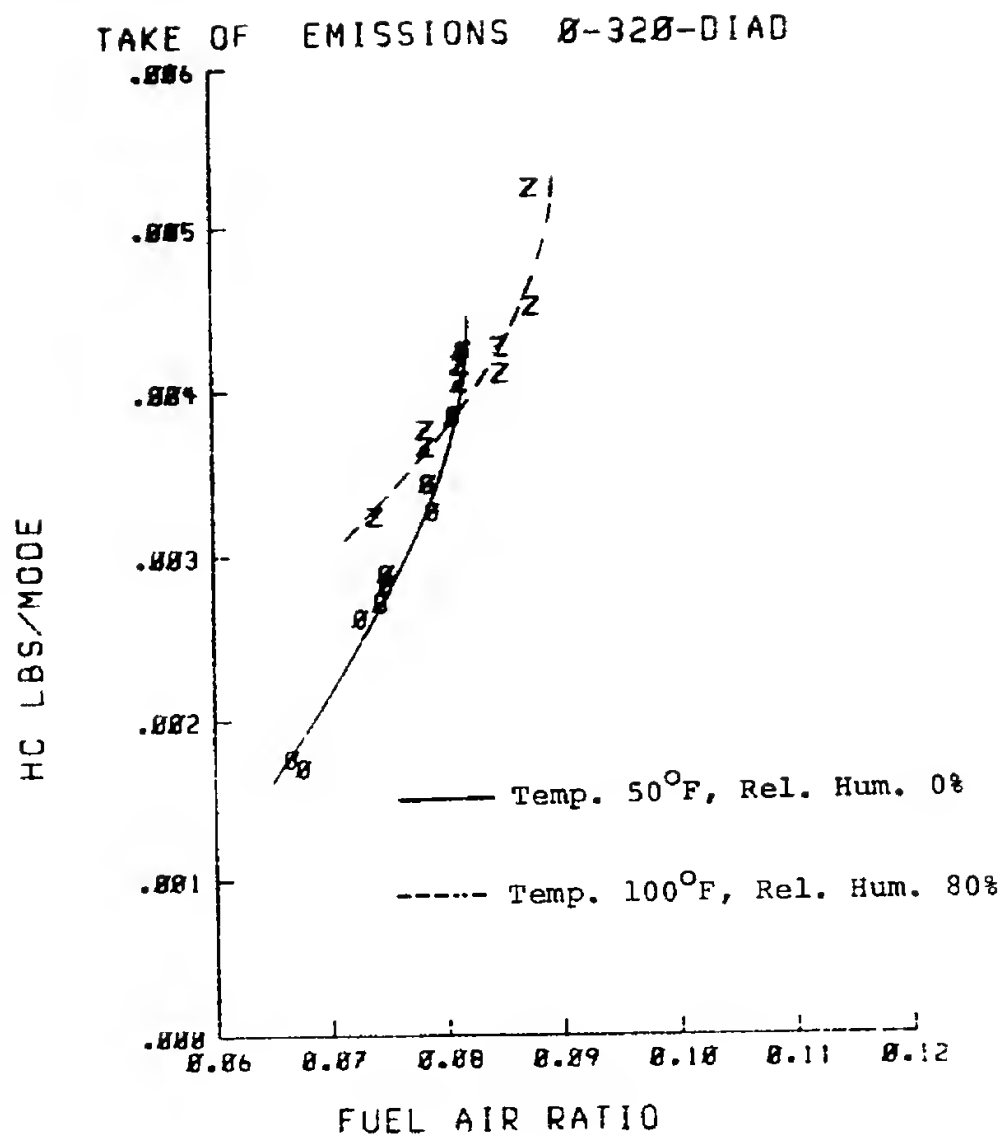


FIGURE 7h

ORIGINAL PAGE IS
OF POOR QUALITY

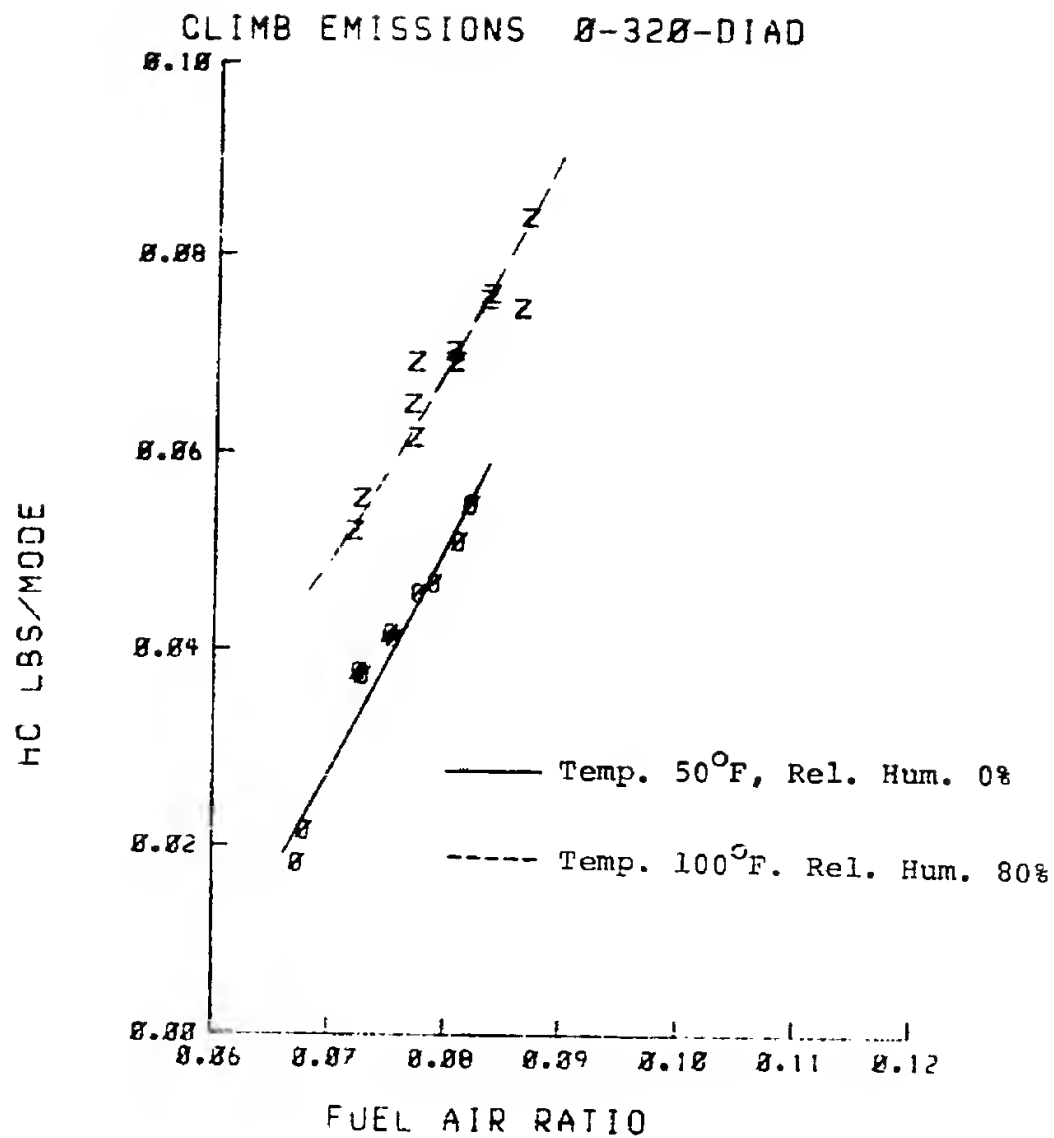


FIGURE 7i

APPROACH EMISSIONS Ø-32Ø-DIAD

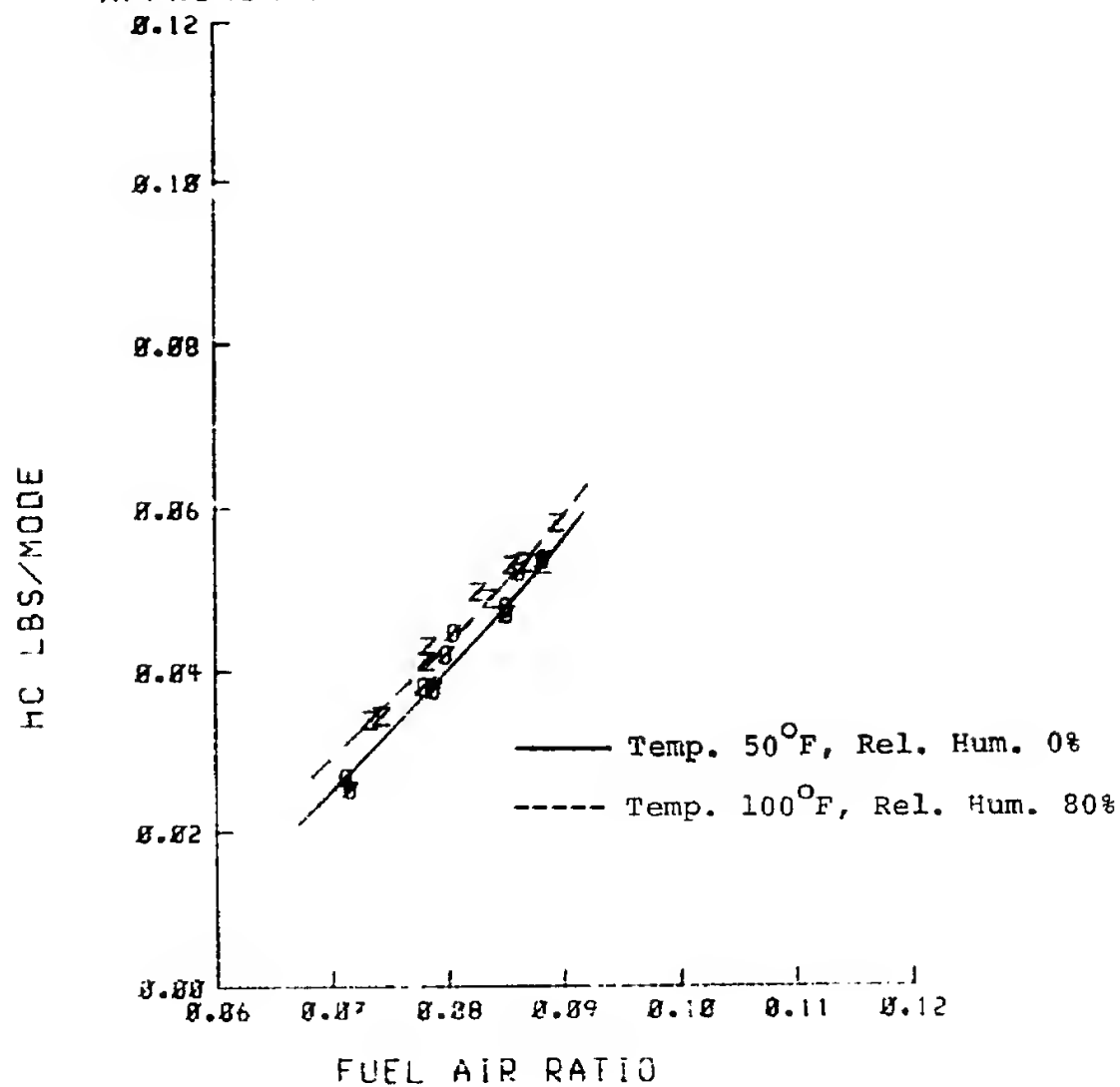


FIGURE 7 j

ORIGINAL PAGE IS
OF POOR QUALITY

IDLE EMISSIONS 8-328-DIAD

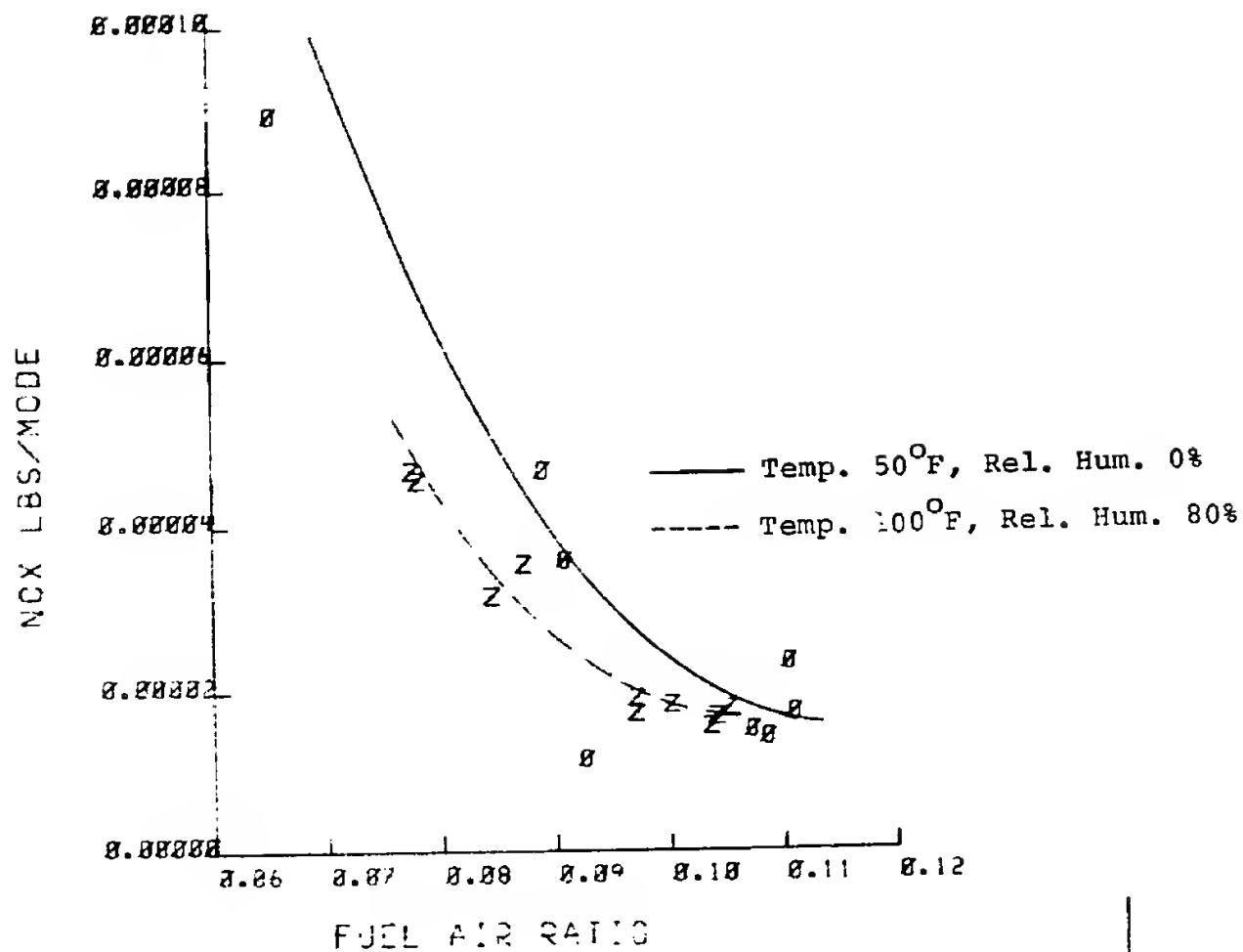
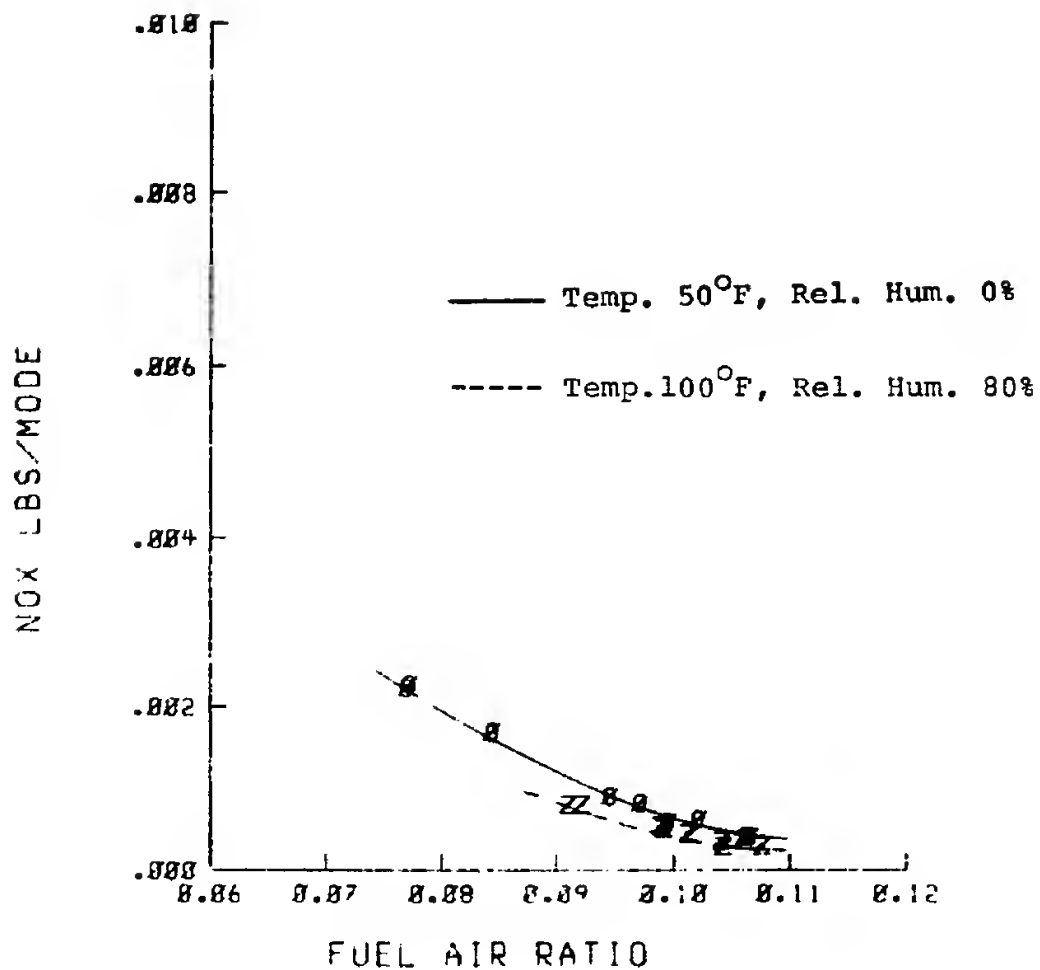


FIGURE 7k

TAXI EMISSIONS Ø-32Ø-DIAD



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FIGURE 71

TAKE OFF EMISSIONS Z-320-DIAD

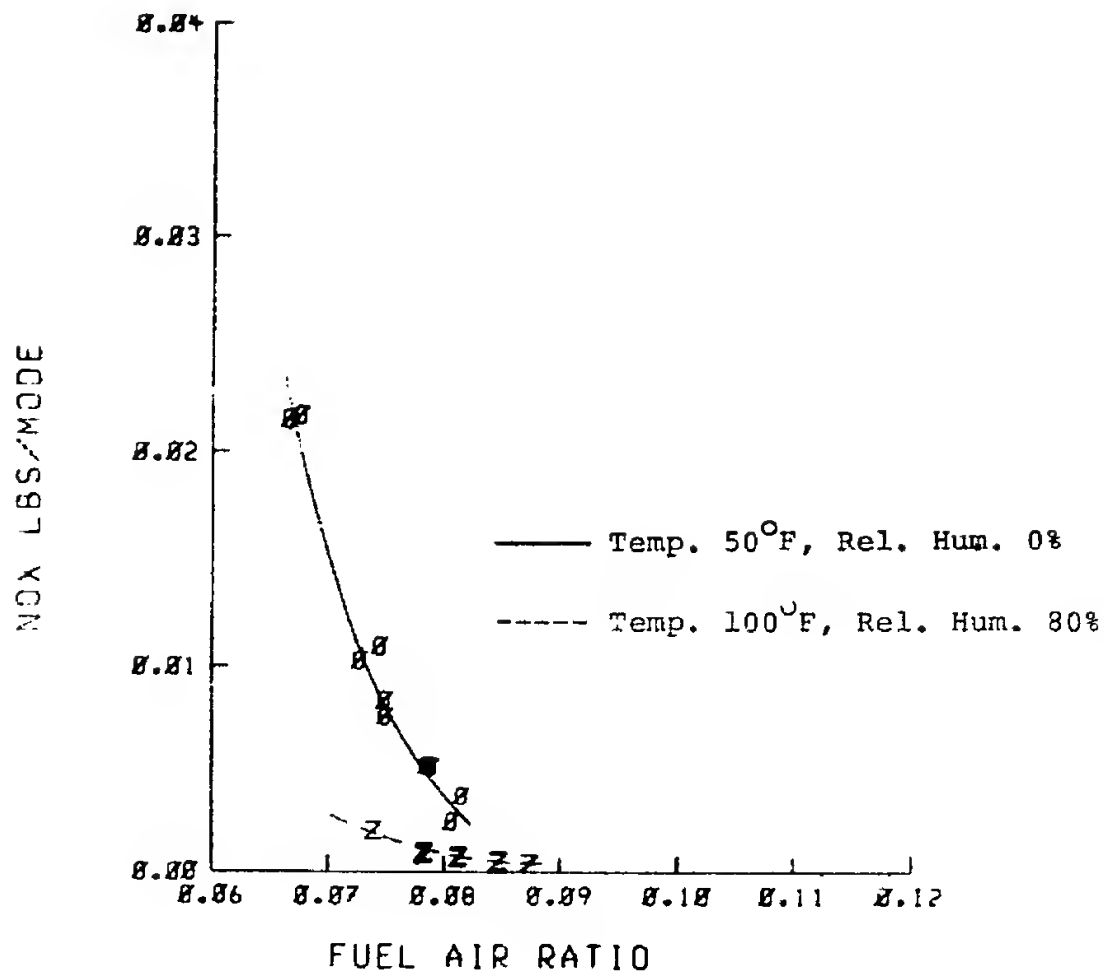


FIGURE 7m

CLIMB EMISSIONS Ø-32Ø-DIAD

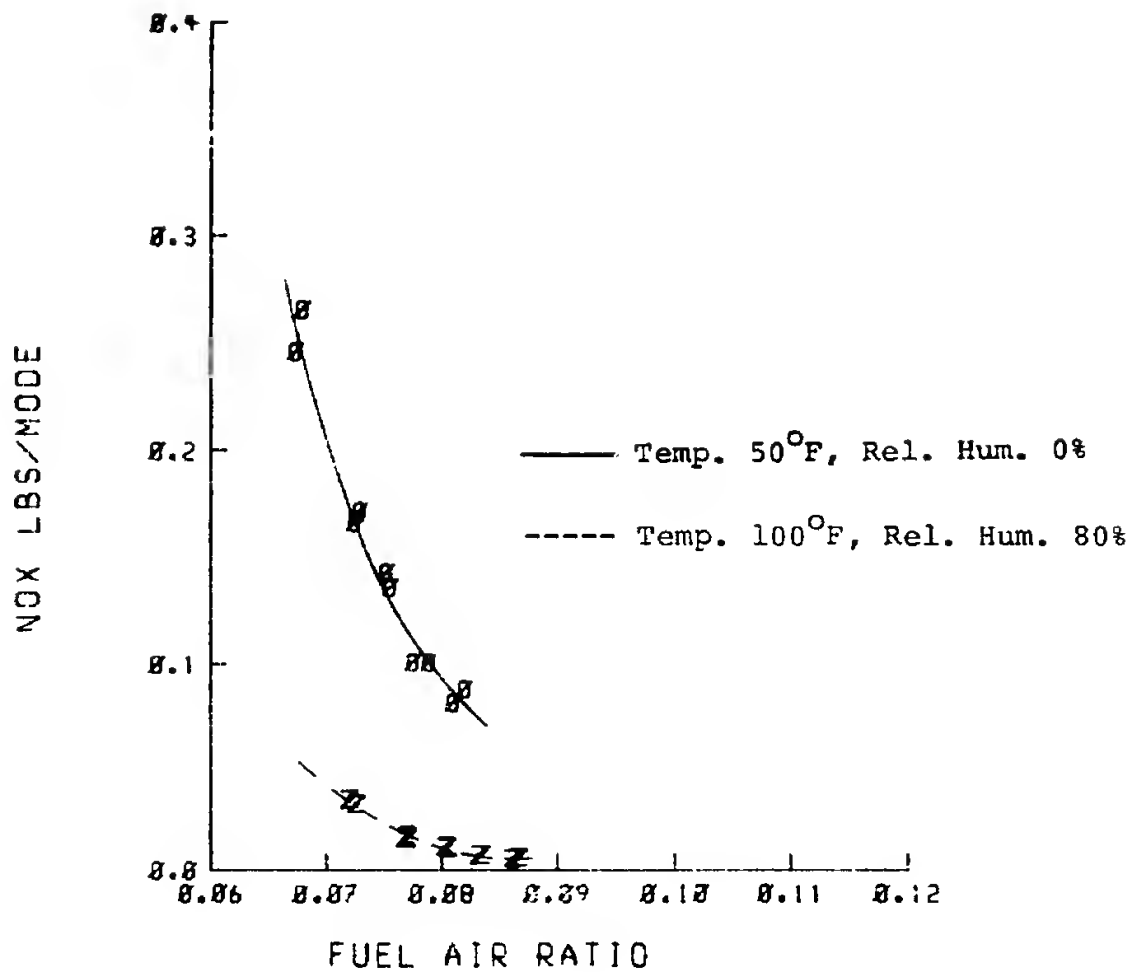


FIGURE 7n

ORIGINAL PAGE IS
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APPROACH EMISSIONS Ø-32Ø-DIAØ

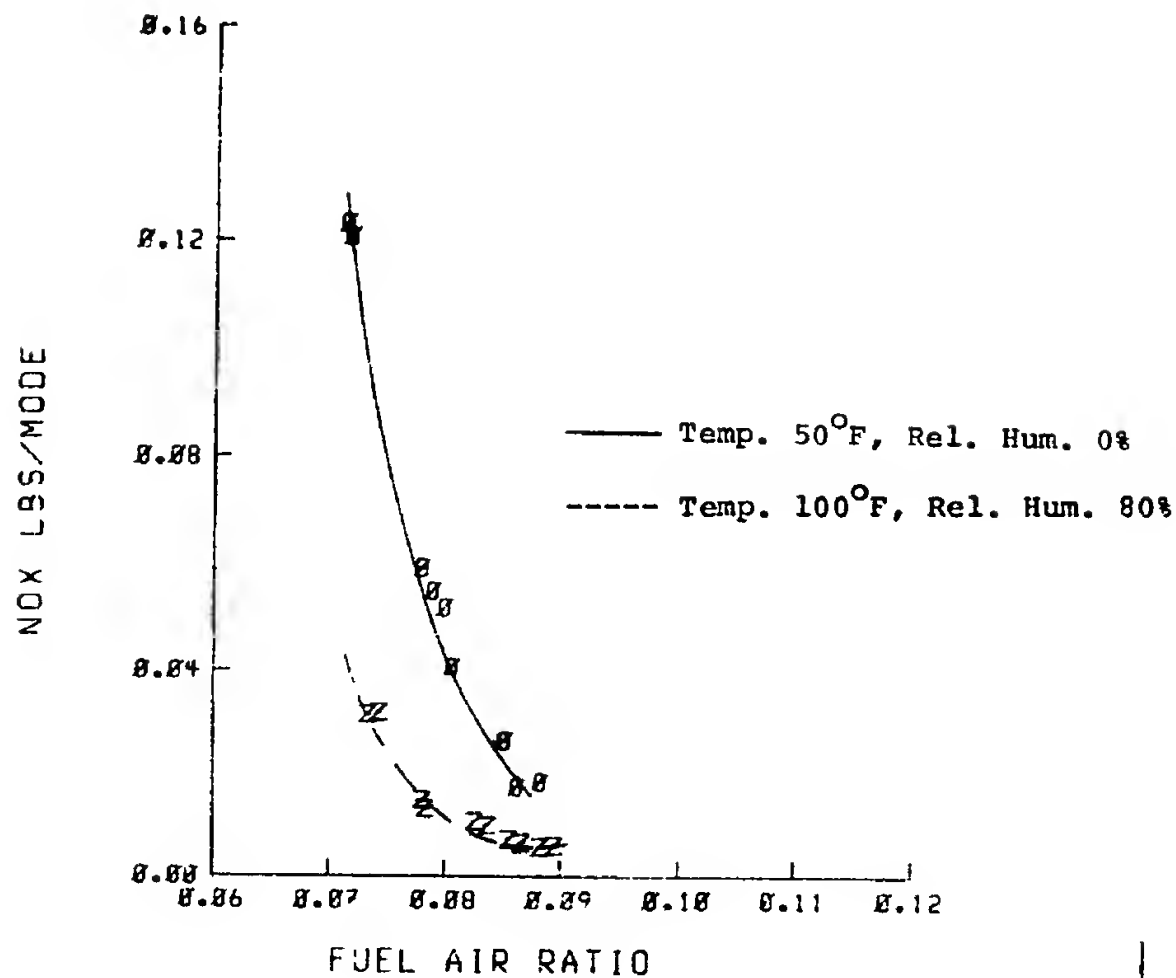


FIGURE 7ø

CO EMISSIONS
 (PERCENT DIFFERENCE BETWEEN
 50°F, 0% R.H. AND 100°F, 80% R.H.)
 FOR VARIOUS FUEL-AIR RATIOS
 AND ENGINE OPERATING MODES

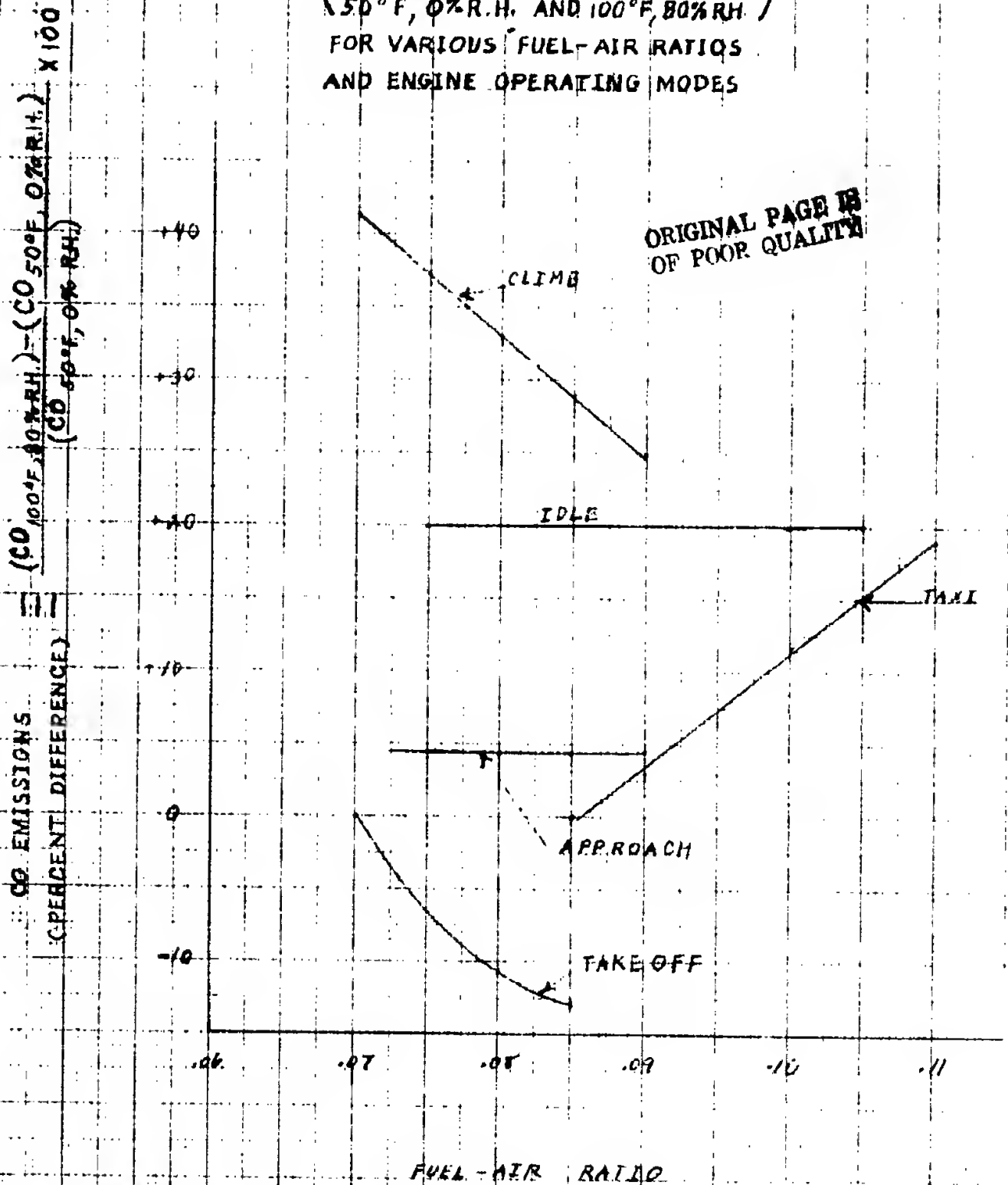


FIGURE 8

HC EMISSIONS

(PERCENT DIFFERENCE BETWEEN
50°F, 0% R.H. AND 100°F, 80% R.H.)
FOR VARIOUS FUEL-AIR RATIOS
AND ENGINE OPERATING MODES

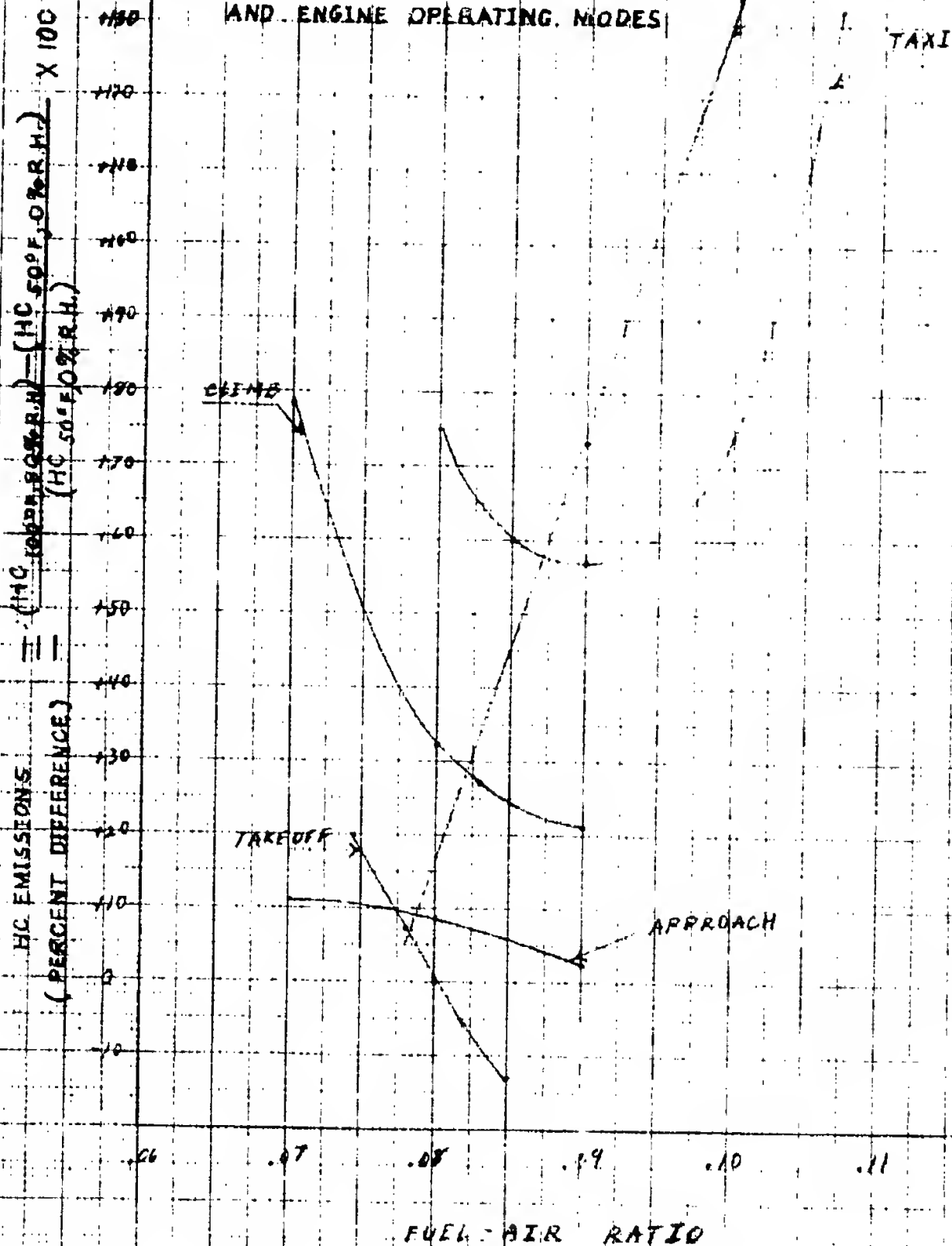


FIGURE 9

NO_x EMISSIONS
 (PERCENT DIFFERENCE BETWEEN
 50°F, 0% RH. AND 100°F, 80% RH.)
 FOR VARIOUS FUEL-AIR RATIOS
 AND ENGINE OPERATING MODES

ORIGINAL PAGE IS
 OF POOR QUALITY

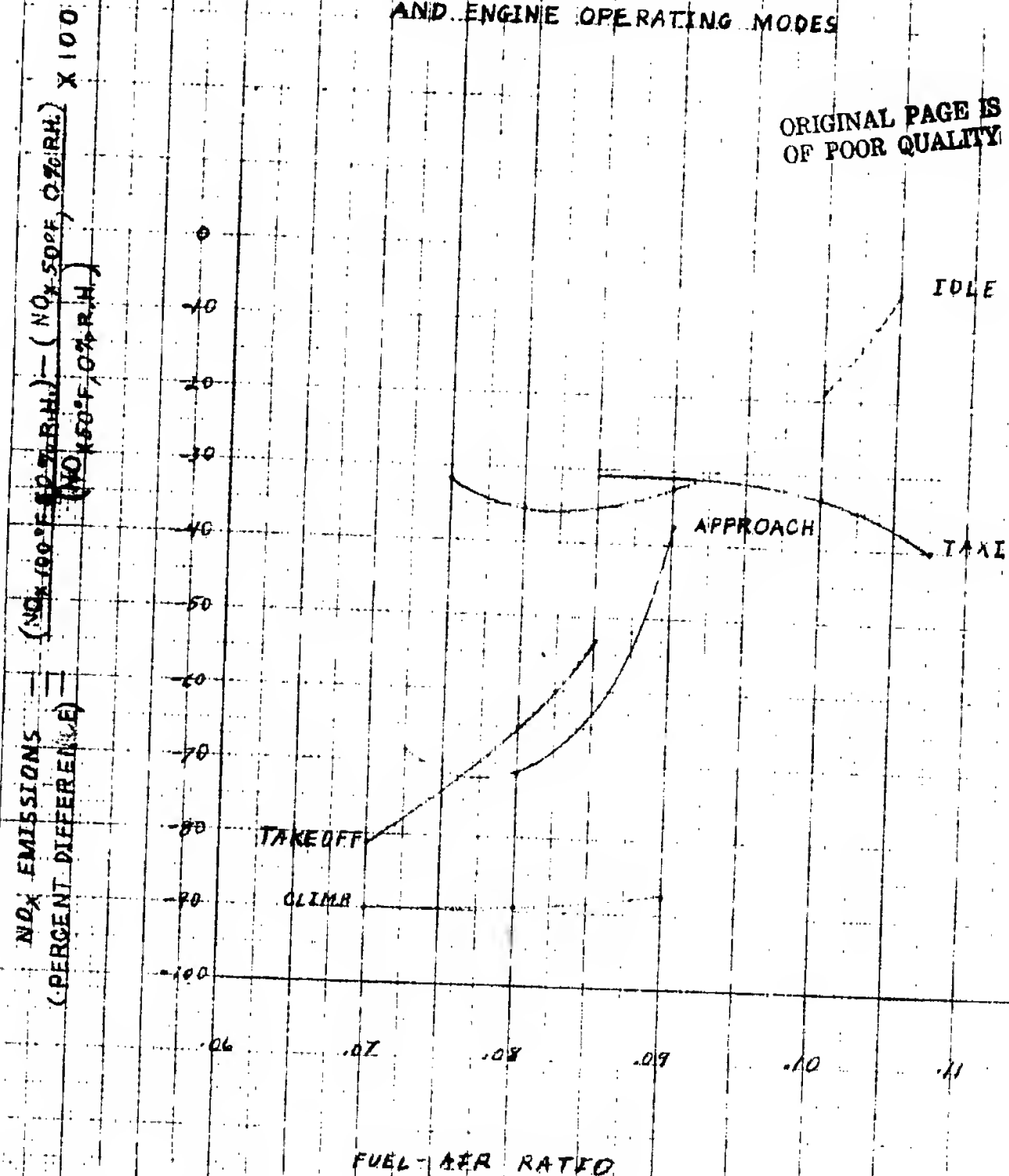
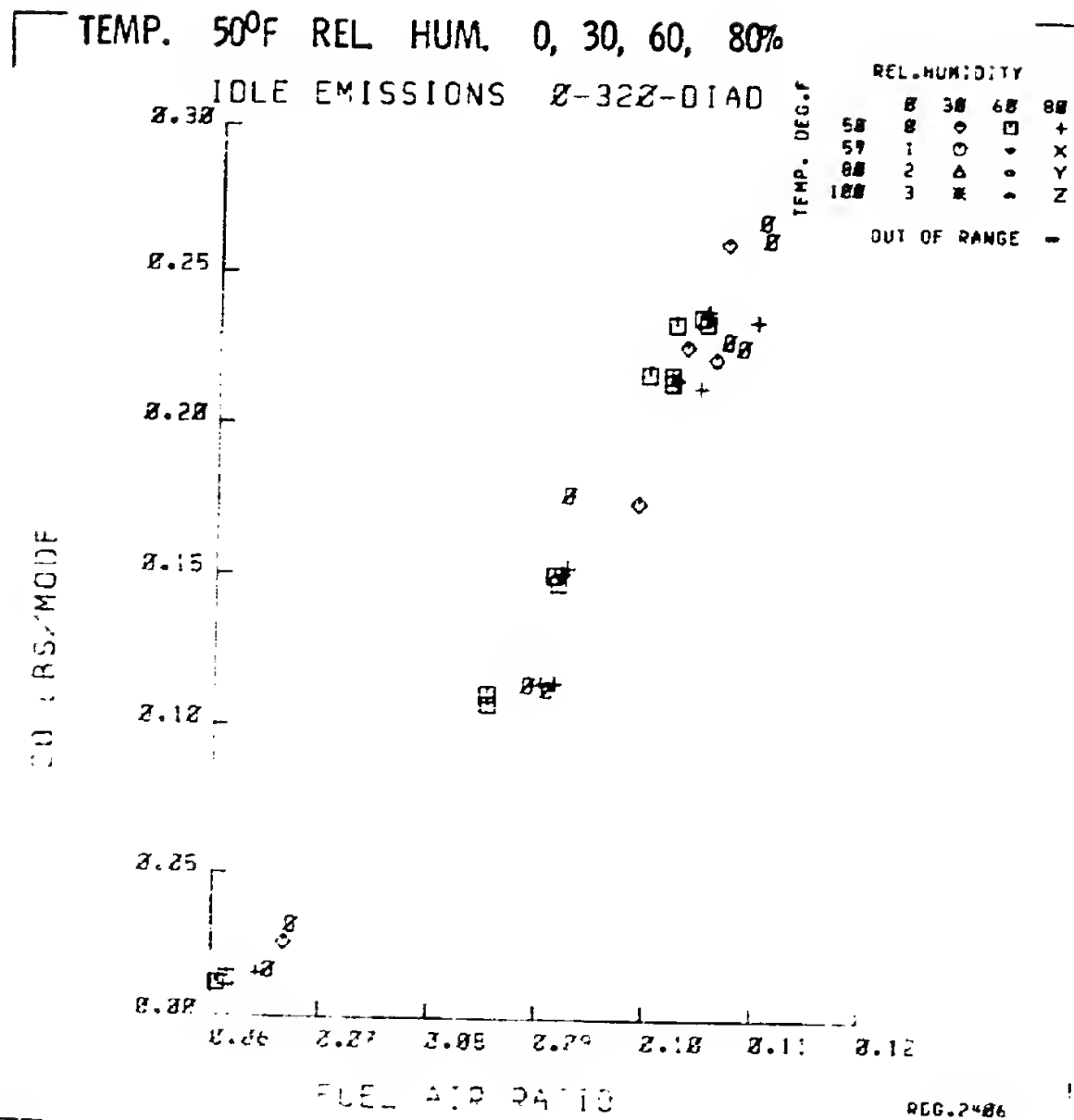


FIGURE 10

NASA LEAN-OUT DATA



IDLE	IDLE
2406	2412
2413	2414
2418	2424
2425	2426
2430	2444
2477	2487
2488	2488
3576	3579
3583	3584
3585	3586
3589	3593
3594	3605
3607	3608
3611	3618
3619	3624
3625	3628
3629	3632
3633	

FIGURE 11a

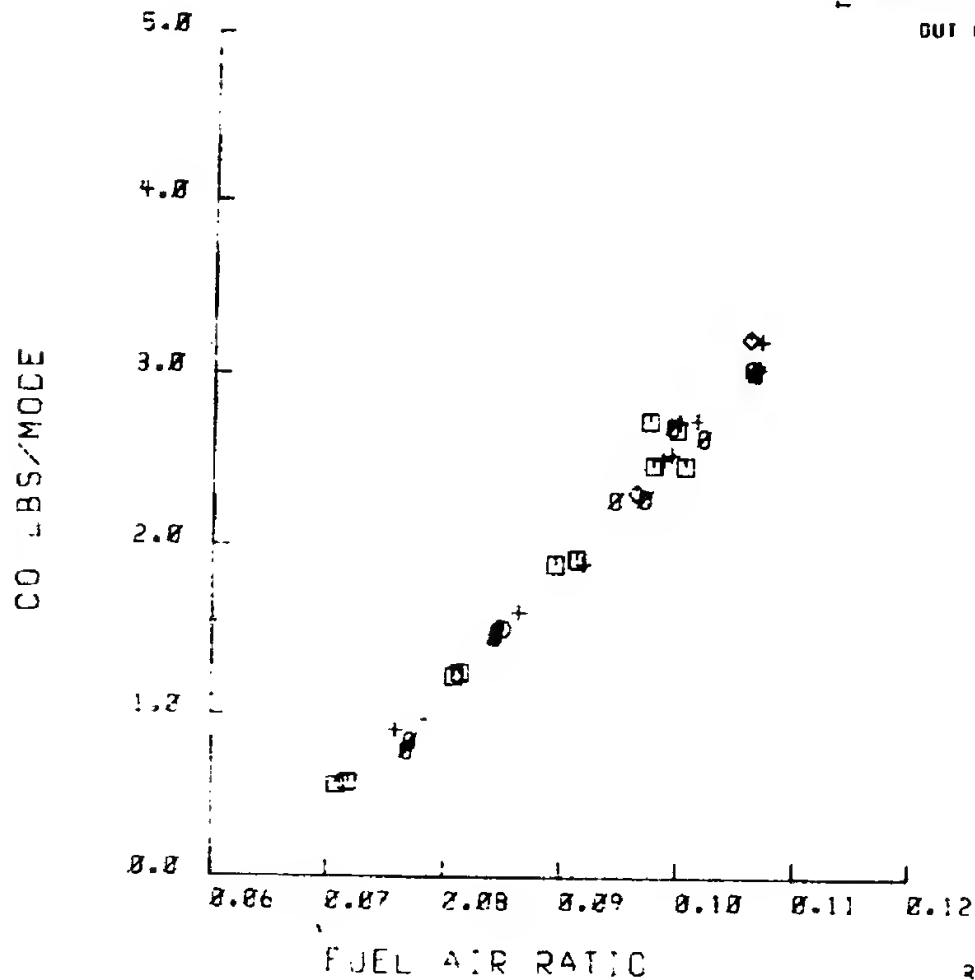
NASA LEAN-OUT DATA

TEMP. 50°F REL HUM. 0, 30, 60, 80%

TAXI EMISSIONS Ø-32Ø-DIAD

TEMP. DEG.F	REL HUMIDITY			
	Ø	3Ø	6Ø	8Ø
5Ø	Ø	Ø	Ø	+
59	1	Ø	Ø	X
8Ø	2	Δ	Ø	Y
1ØØ	3	■	▲	Z

OUT OF RANGE --



TAXI
2403
2409
2415 Ø
2420
2427
2465
2490 ◇
3578
3582
3588 □
3592
3610
3614
3623
3627 +
3631
3635

TAXI
2405
2411 Ø
2417
2423
2429
2469 ◇
3577
3581
3587 □
3591
3609
3613
3620
3626 +
3630
3634

ORIGINAL PAGE IS
OF POOR QUALITY

FIGURE 11b

NASA LEAN-OUT DATA

TEMP. 50°F REL HUM. 0, 30, 60, 80%

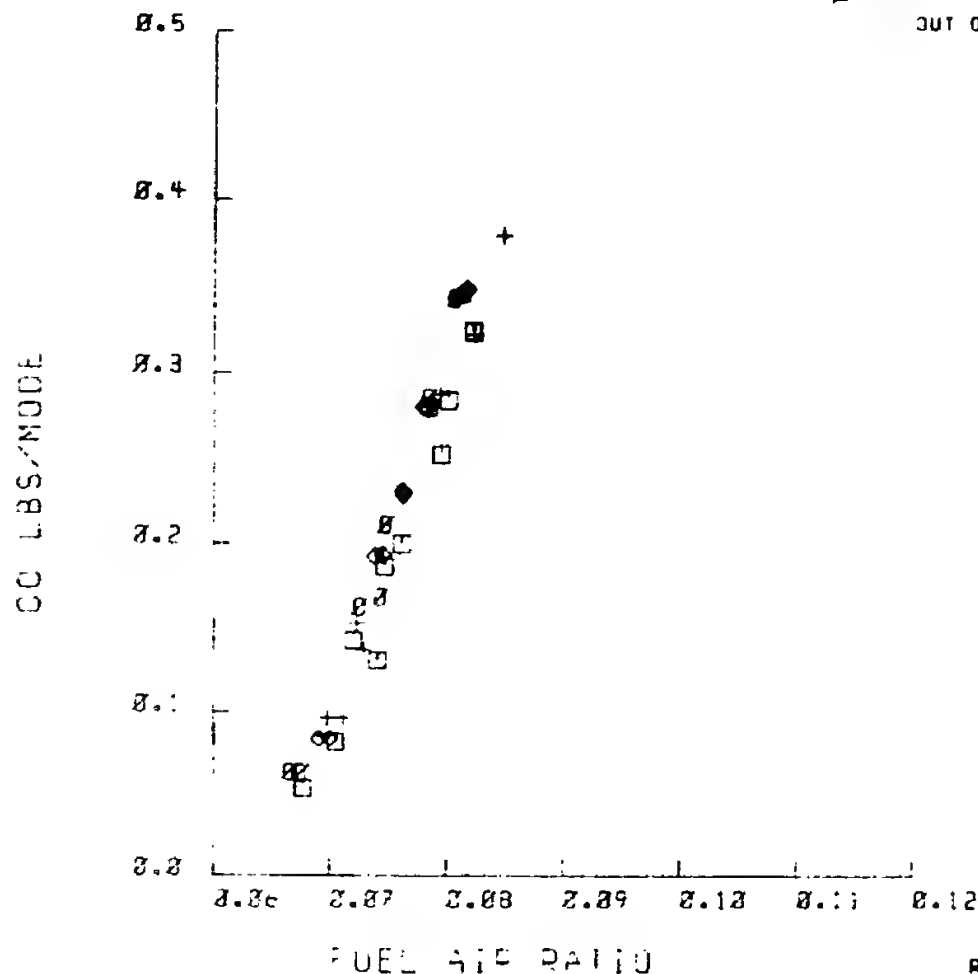
TAKE OFF EMISSIONS Ø-32Ø-DIAD

REL. HUMIDITY

	Ø	3Ø	6Ø	ØØ
5Ø	Ø	Ø	Ø	+
59	1	Ø	Ø	X
ØØ	2	Δ	Ø	Y
1ØØ	3	■	■	Z

TEMP. DEG.F

OUT OF RANGE -



TAKE-OFF
2431
2438
2445 Ø
2452
2458
2494
2501
2507 Ø
2514
2521
3639
3643
3652 □
3658
3664
3668
3674
3686 +
3692

TAKE-OFF
2435
2442 Ø
2448 Ø
2455
2461
2498
2504
2511 Ø
2517
2524
3640
3649
3655 □
3661
3667
3671
3680
3689 +
3695

RDC.2431

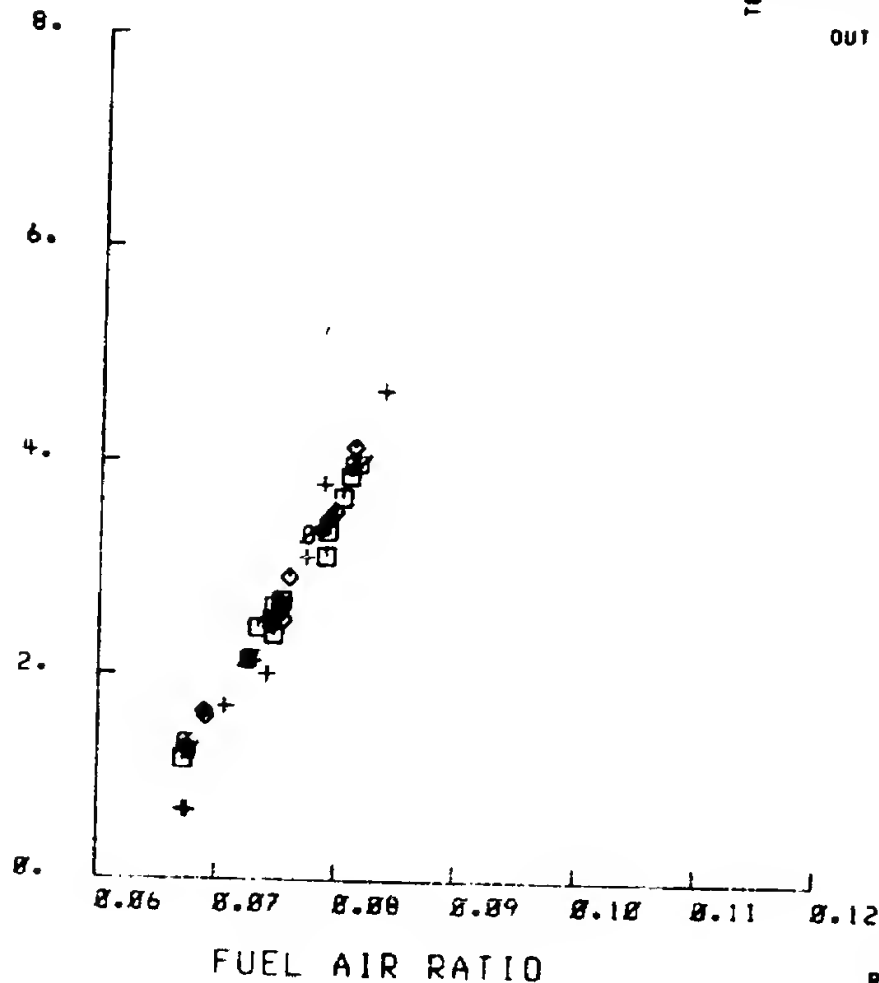
NASA LEAN-OUT DATA

TEMP. 50°F REL HUM. 0, 30, 60, 80%

CLIMB EMISSIONS Ø-32Ø-DIAD

TEMP. DEG.F	REL.HUMIDITY			
	0	30	60	80
	Ø	Ø	Ø	+
	1	Ø	Ø	X
	2	Δ	Ø	Y
100	3	Δ	Δ	Z
OUT OF RANGE -				

CO LBS/MODE



ORIGINAL PAGE IS
A POOR QUALITY

CLIMB

2433
2439
2446 Ø
2453
2459
2495
2502
2512 Ø
2519
2525
3641
3647
3653 Ø
3659
3665
3672
3678
3684 +
3690
3696

CLIMB

2436
2443
2449 Ø
2456
2462
2499
2505
2515 Ø
2522
3637
3644
3650 Ø
3656
3662
3669
3675
3681 +
3687
3693

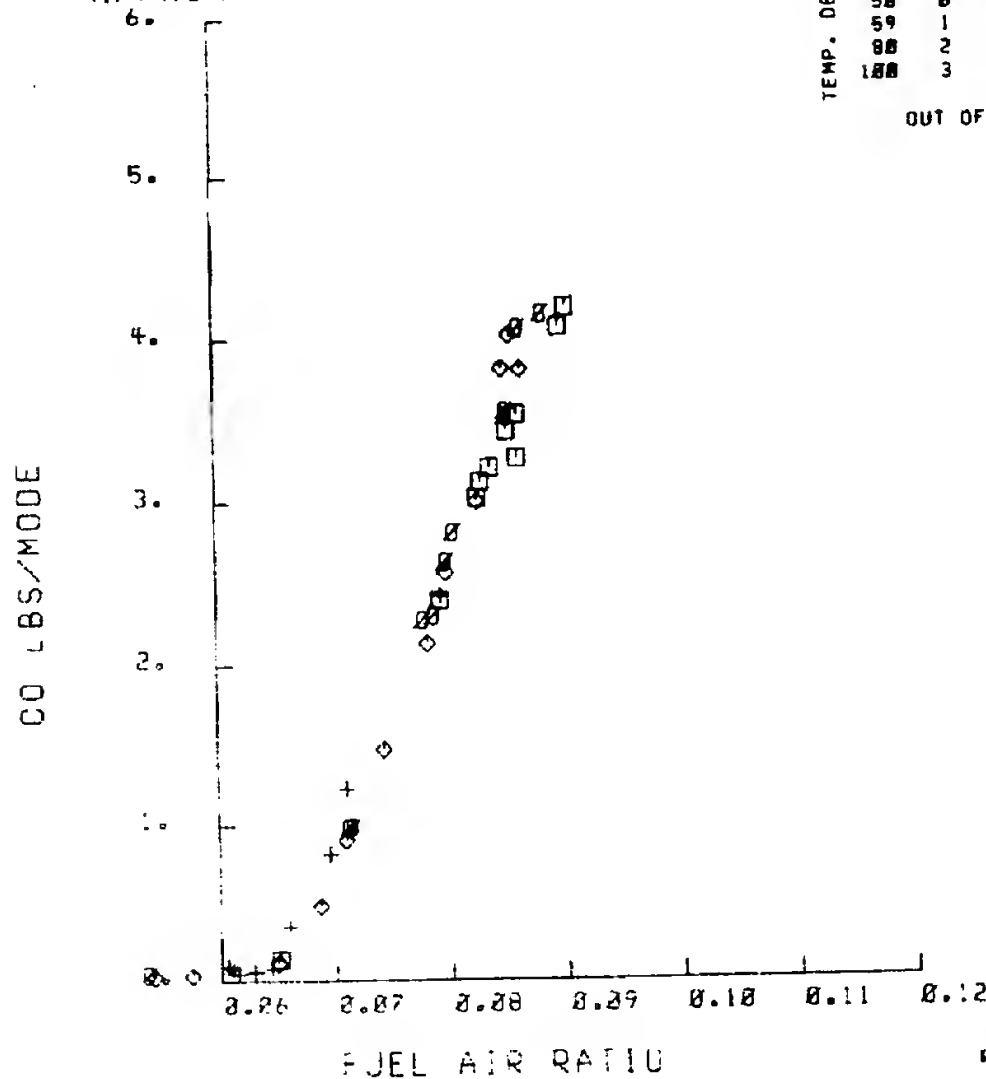
FIGURE 11a

RD0.2433

NASA LEAN-OUT DATA

TEMP. 50°F REL HUM 0, 30, 60, 80%

APPROACH EMISSIONS Ø-32Ø-DIAD



APPROACH

2434
2441
2447 Ø
2454
2460
2496
3562
3564
3566
3568
3570
3638
3645
3651
3657
3663
3670
3676
3685 +
3691
3697

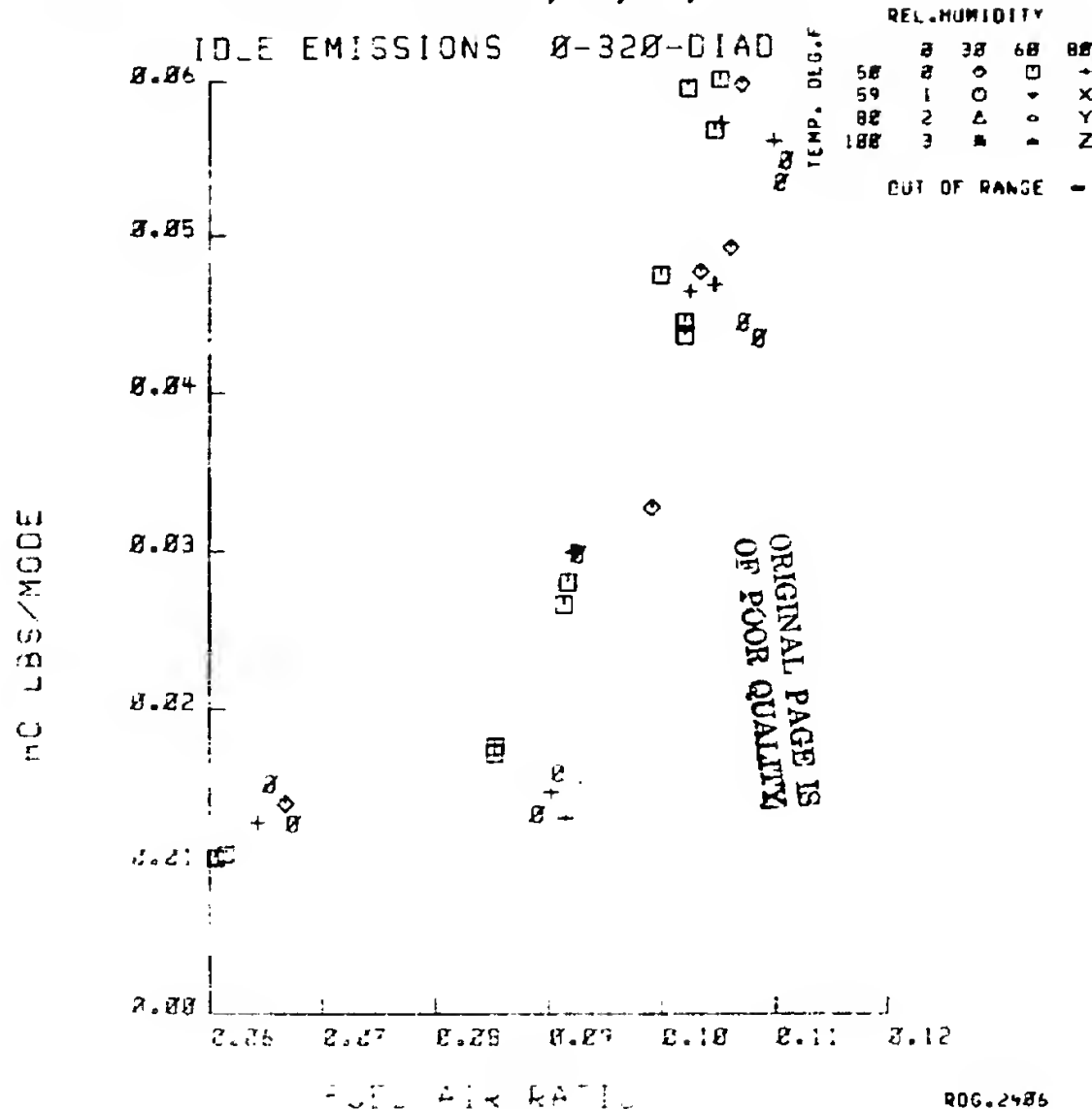
APPROACH

2437
2444
2450 Ø
2457
2463
3561
3563
3565
3567
3569
3571
3642
3648
3654
3660
3666
3673
3679
3688 +
3694

FIGURE 11e

NASA LEAN-OUT DATA

TEMP. 50°F REL HUM. 0, 30, 60, 80%



IDLE	IDLE
2406	2412
2413	2414
2418	2424
2425	2426
2430	2426
2477	2427
2488	2480
3576	3579
3583	3584
3585	3586
3589	3593
3594	3605
3607	3608
3611	3618
3619	3624
3625	3628
3629	3632
3633	

FIGURE 11f

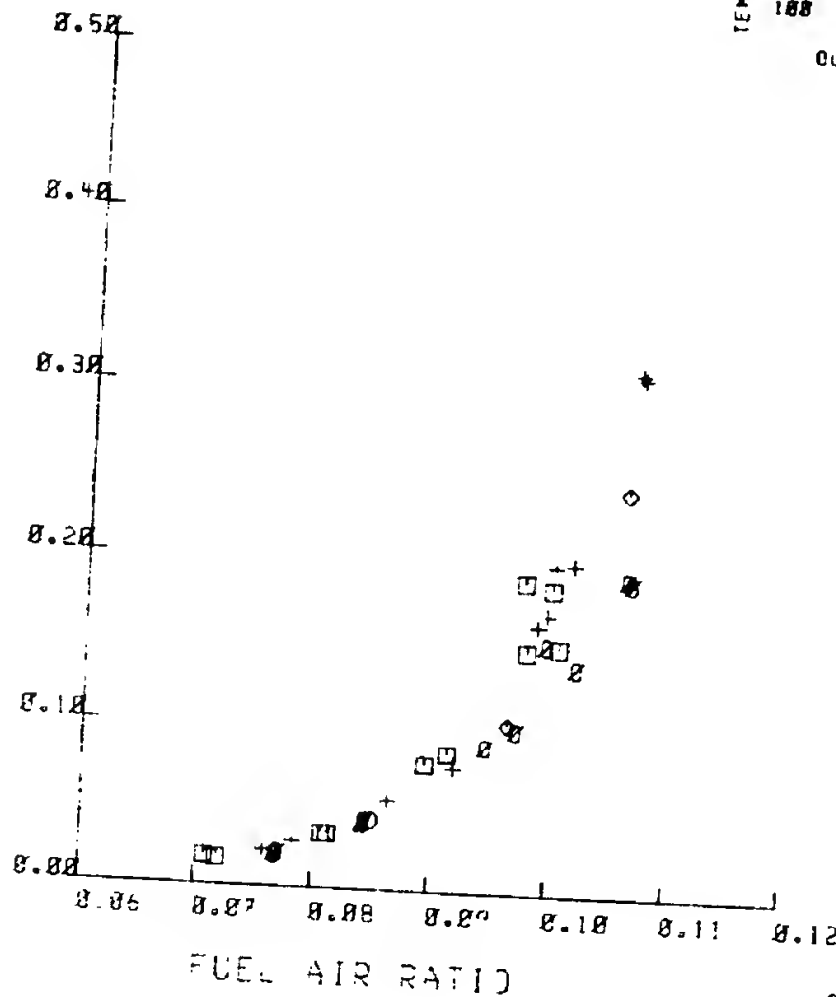
NASA LEAN-OUT DATA

TEMP. 50°F REL HUM. 0, 30, 60, 80%

TAXI EMISSIONS 8-328-DIAD

TEMP. DEG.F	REL.HUMIDITY			
	8	38	68	88
58	8	○	□	+
59	:	○	▽	X
88	2	△	○	Y
188	3	▲	▲	Z
OUT OF RANGE -				

PC LBS/MODE



RDG. 2403

TAXI
2403
2409
2415
2420
2427
2465
2490
3578
3582
3588
3592
3610
3614
3623
3627
3631
3635

TAXI
2405
2411
2417
2423
2429
2469
3577
3581
3587
3591
3609
3613
3620
3626
3630
3634

FIGURE 11g

NASA LEAN-OUT DATA

TEMP. 50°F REL HUM. 0, 30, 60, 80%

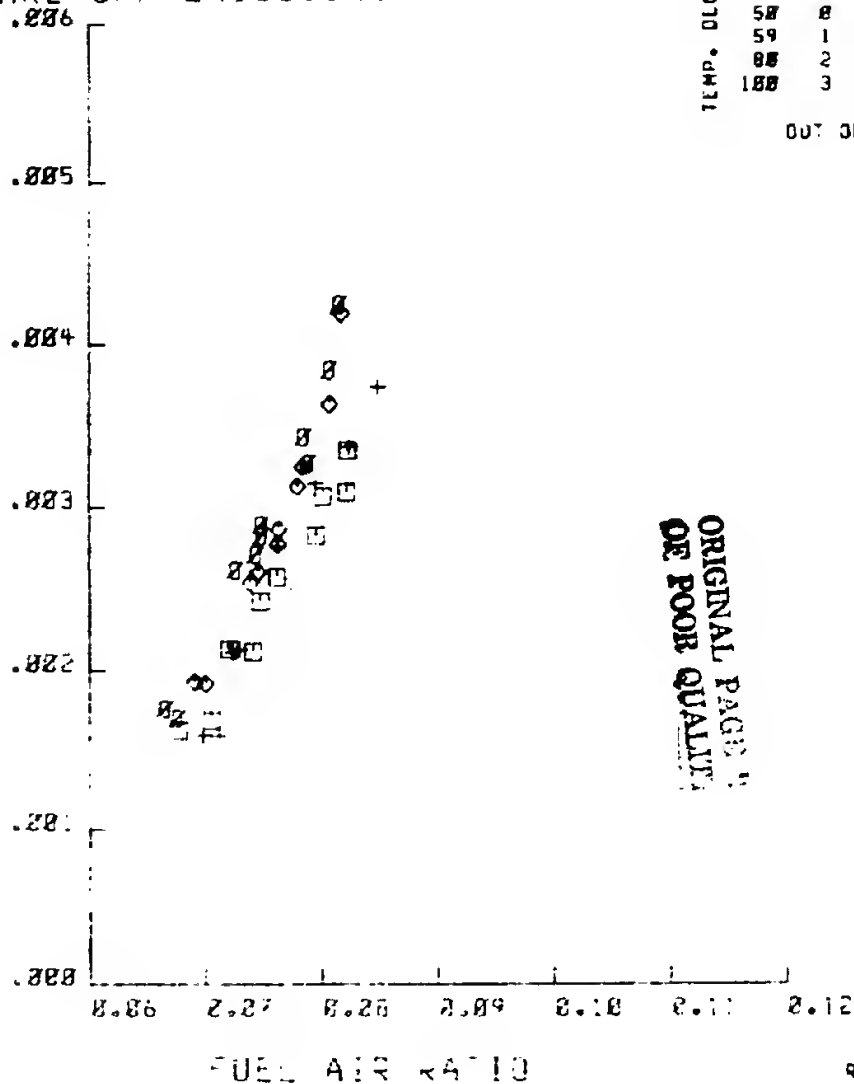
TAKE OFF EMISSIONS Ø-32Ø-DIAD

REL. HUMIDITY

TEMP. DEG. F	Ø	30	60	80
50	Ø	Ø	Ø	+
59	1	Ø	Ø	X
88	2	Δ	Ø	Y
100	3	✱	Ø	7

OUT OF RANGE -

HC LBS/NODE



TAKE-OFF

2431
2439
2445 Ø
2452
2459
2474
2501
2507 Ø
2514
2521
3639
3643
3652 □
3658
3664
3669
3674 +
3686 +
3692

TAKE-OFF

2435
2442
2449 Ø
2455
2461
2498
2504
2511 Ø
2517
2524
3640
3649
3655 □
3661
3667
3671
3680
3689 +
3695

REC-2431

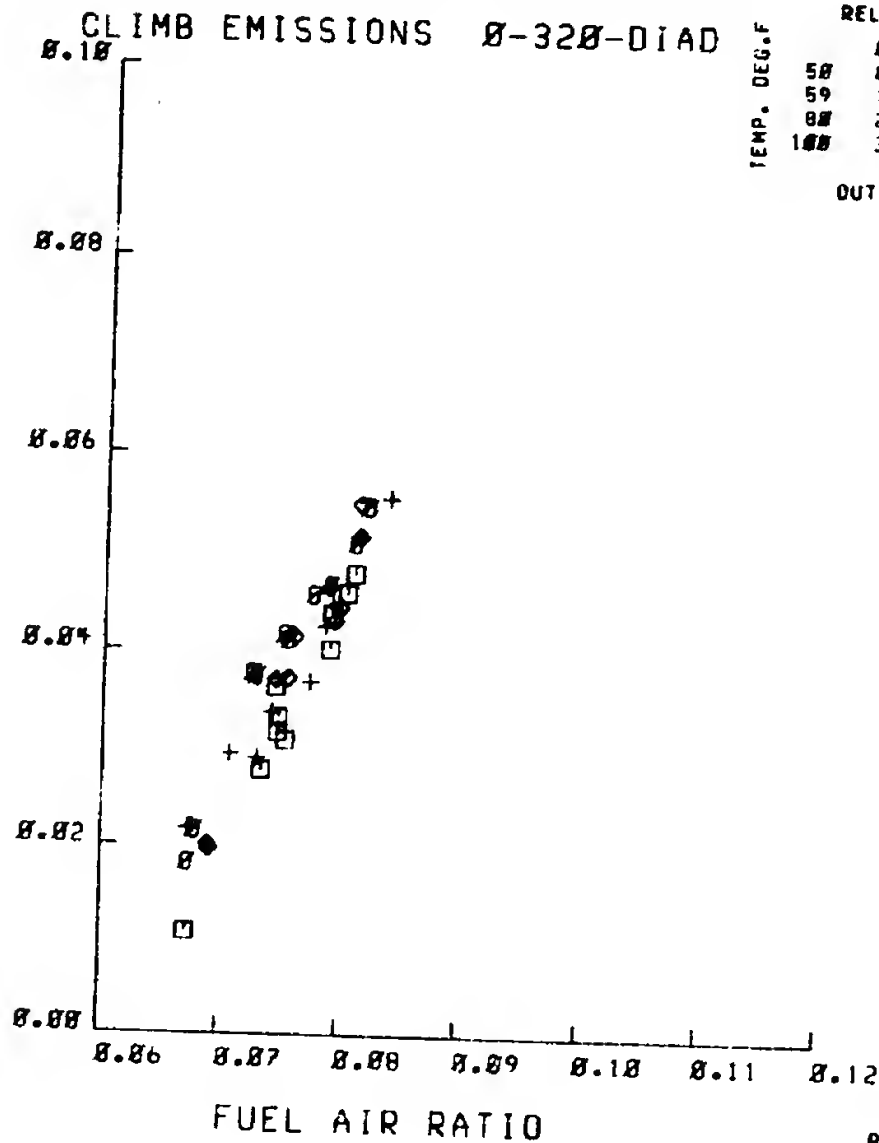
FIGURE 11h

NASA LEAN-OUT DATA

TEMP. 50°F REL HUM. 0, 30, 60, 80%

CLIMB EMISSIONS B-32B-DIAD

HC LBS/MODE



CLIMB

2433
2439
2446 ϕ
2453
2459
2495
2502
2512 ϕ
2519
2525
3641
3647
3653 \square
3659
3665
3672
3678
3684 +
3690
3696

CLIMB

2436
2443
2449 ϕ
2456
2462
2499
2505
2515 ϕ
2522
3637
3644
3650 \square
3656
3662
3669
3675
3681 +
3687
3693

ROC.2433

FIGURE 111

NASA LEAN-OUT DATA

TEMP. 50°F REL HUM. 0, 30, 60, 80%

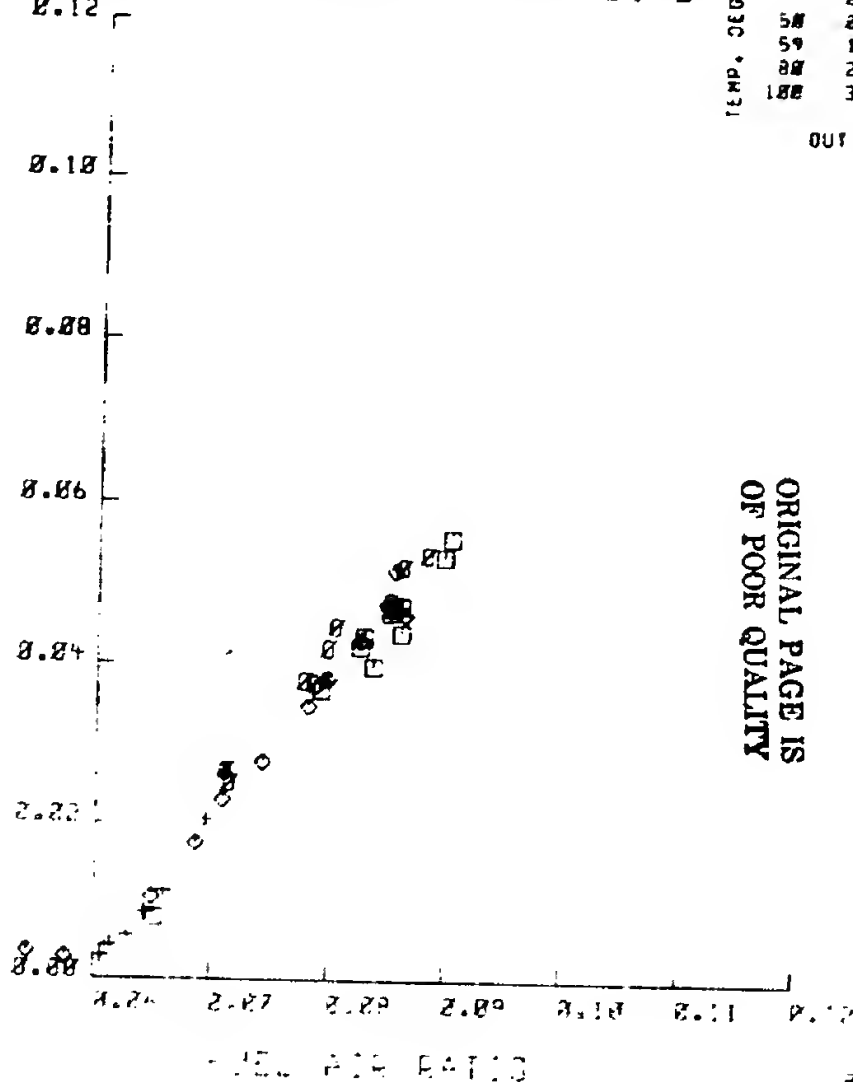
APPROACH EMISSIONS Ø-32Ø-DIAD

REL. HUMIDITY

TEMP. °C (°F)	Ø	3Ø	6Ø	8Ø
5Ø	Ø	Ø	Ø	+
59	1	Ø	Ø	X
88	2	Δ	Ø	Y
188	3	Δ	Ø	Z

OUT OF RANGE -

CO LBS-MODE



APPROACH

2434
2441
2447 Ø
2454
2467
2496
3562
3564 Ø
3566
3568
3570
3638
3645
3651 Ø
3657
3663
3670
3676
3685 +
3691
3697

APPROACH

2437
2444
2450 Ø
2457
2453
3561
3563
3565 Ø
3567
3569
3571
3642
3648
3654 Ø
3660
3666
3673
3679
3688 +
3694

FIGURE 11j

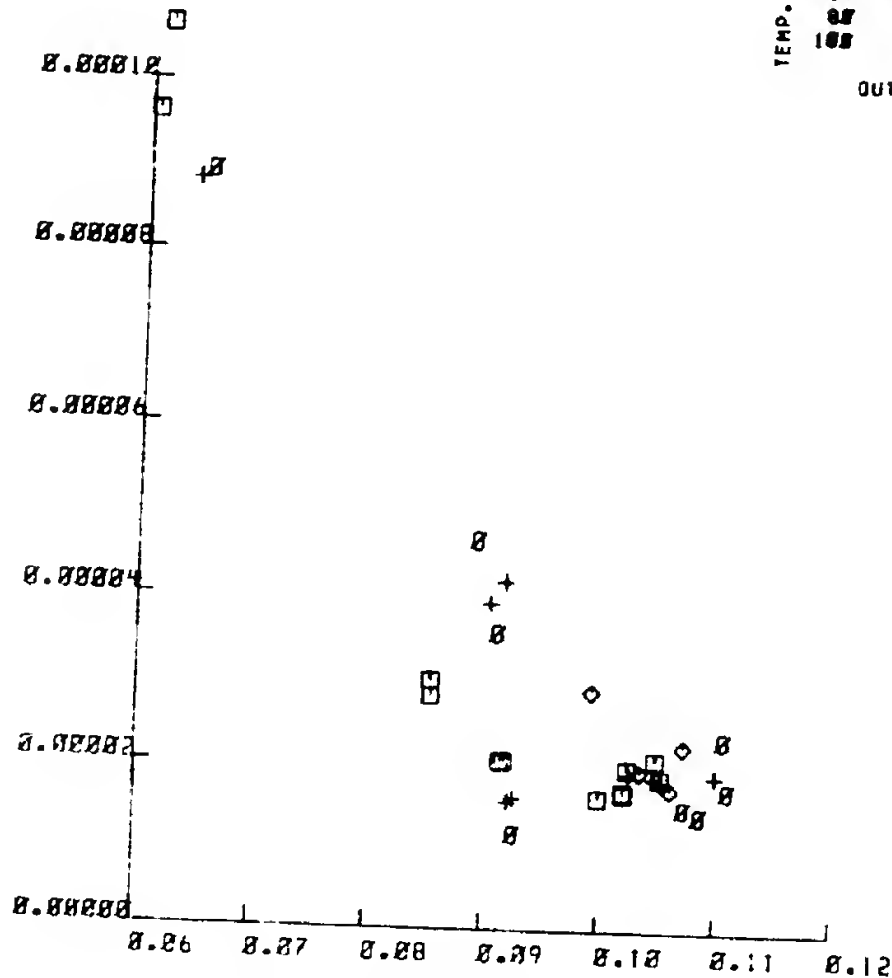
NASA LEAN-OUT DATA

TEMP. 50°F REL HUM. 0, 30, 60, 80%

IDLE EMISSIONS Ø-32Ø-DIAD

REL. HUMIDITY
 0 30 60 80
 50 0 0 0 0
 59 1 0 0 0
 68 2 0 0 0
 100 3 0 0 0
 OUT OF RANGE -

NOX LBS/MODE



RDG. 2486

IDLE
2406
2413
2418 Ø
2425
2430
2477
2488 Ø
3576
3583
3585 □
3589
3594
3607
3611
3619
3625 +
3629
3633

IDLE
2412
2414 Ø
2424 Ø
2426
2464
2487 Ø
2489
3579
3584
3586
3593 □
3605
3608
3618
3624
3628 +
3632

FIGURE 11k

NASA LEAN-OUT DATA

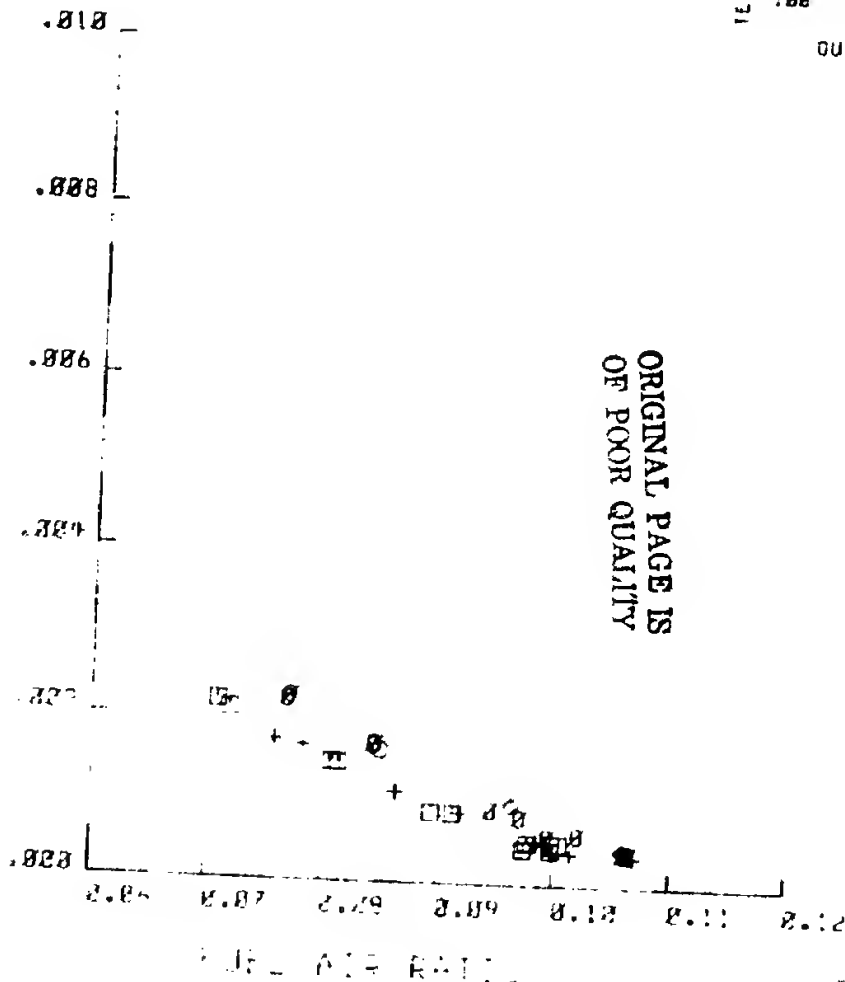
TEMP. 50°F REL HUM. 0, 30, 60, 80%

TAXI EMISSIONS 0-320-CIAD

TEMP. DEG.F	REL. HUMIDITY
58	0
59	1
60	2
61	3
62	4
63	5
64	6
65	7
66	8
67	9
68	0
69	1
70	2
71	3
72	4
73	5
74	6
75	7
76	8
77	9
78	0
79	1
80	2
81	3
82	4
83	5
84	6
85	7
86	8
87	9
88	0
89	1
90	2
91	3
92	4
93	5
94	6
95	7
96	8
97	9
98	0
99	1
100	2
101	3
102	4
103	5
104	6
105	7
106	8
107	9
108	0
109	1
110	2
111	3
112	4
113	5
114	6
115	7
116	8
117	9
118	0
119	1
120	2
121	3
122	4
123	5
124	6
125	7
126	8
127	9
128	0
129	1
130	2
131	3
132	4
133	5
134	6
135	7
136	8
137	9
138	0
139	1
140	2
141	3
142	4
143	5
144	6
145	7
146	8
147	9
148	0
149	1
150	2
151	3
152	4
153	5
154	6
155	7
156	8
157	9
158	0
159	1
160	2
161	3
162	4
163	5
164	6
165	7
166	8
167	9
168	0
169	1
170	2
171	3
172	4
173	5
174	6
175	7
176	8
177	9
178	0
179	1
180	2
181	3
182	4
183	5
184	6
185	7
186	8
187	9
188	0
189	1
190	2
191	3
192	4
193	5
194	6
195	7
196	8
197	9
198	0
199	1
200	2
201	3
202	4
203	5
204	6
205	7
206	8
207	9
208	0
209	1
210	2
211	3
212	4
213	5
214	6
215	7
216	8
217	9
218	0
219	1
220	2
221	3
222	4
223	5
224	6
225	7
226	8
227	9
228	0
229	1
230	2
231	3
232	4
233	5
234	6
235	7
236	8
237	9
238	0
239	1
240	2
241	3
242	4
243	5
244	6
245	7
246	8
247	9
248	0
249	1
250	2
251	3
252	4
253	5
254	6
255	7
256	8
257	9
258	0
259	1
260	2
261	3
262	4
263	5
264	6
265	7
266	8
267	9
268	0
269	1
270	2
271	3
272	4
273	5
274	6
275	7
276	8
277	9
278	0
279	1
280	2
281	3
282	4
283	5
284	6
285	7
286	8
287	9
288	0
289	1
290	2
291	3
292	4
293	5
294	6
295	7
296	8
297	9
298	0
299	1
300	2
301	3
302	4
303	5
304	6
305	7
306	8
307	9
308	0
309	1
310	2
311	3
312	4
313	5
314	6
315	7
316	8
317	9
318	0
319	1
320	2
321	3
322	4
323	5
324	6
325	7
326	8
327	9
328	0
329	1
330	2
331	3
332	4
333	5
334	6
335	7
336	8
337	9
338	0
339	1
340	2
341	3
342	4
343	5
344	6
345	7
346	8
347	9
348	0
349	1
350	2
351	3
352	4
353	5
354	6
355	7
356	8
357	9
358	0
359	1
360	2
361	3
362	4
363	5
364	6
365	7
366	8
367	9
368	0
369	1
370	2
371	3
372	4
373	5
374	6
375	7
376	8
377	9
378	0
379	1
380	2
381	3
382	4
383	5
384	6
385	7
386	8
387	9
388	0
389	1
390	2
391	3
392	4
393	5
394	6
395	7
396	8
397	9
398	0
399	1
400	2
401	3
402	4
403	5
404	6
405	7
406	8
407	9
408	0
409	1
410	2
411	3
412	4
413	5
414	6
415	7
416	8
417	9
418	0
419	1
420	2
421	3
422	4
423	5
424	6
425	7
426	8
427	9
428	0
429	1
430	2
431	3
432	4
433	5
434	6
435	7
436	8
437	9
438	0
439	1
440	2
441	3
442	4
443	5
444	6
445	7
446	8
447	9
448	0
449	1
450	2
451	3
452	4
453	5
454	6
455	7
456	8
457	9
458	0
459	1
460	2
461	3
462	4
463	5
464	6
465	7
466	8
467	9
468	0
469	1
470	2
471	3
472	4
473	5
474	6
475	7
476	8
477	9
478	0
479	1
480	2
481	3
482	4
483	5
484	6
485	7
486	8
487	9
488	0
489	1
490	2
491	3
492	4
493	5
494	6
495	7
496	8
497	9
498	0
499	1
500	2

OUT OF RANGE -

VOX LBS/MODE



TAXI
2403
2409
2415
2420
2427
2465
2490
3578
3582
3588
3592
3610
3614
3623
3627
3631
3635

TAXI
2405
2411
2417
2423
2429
2469
3577
3581
3587
3591
3609
3613
3620
3626
3630
3634

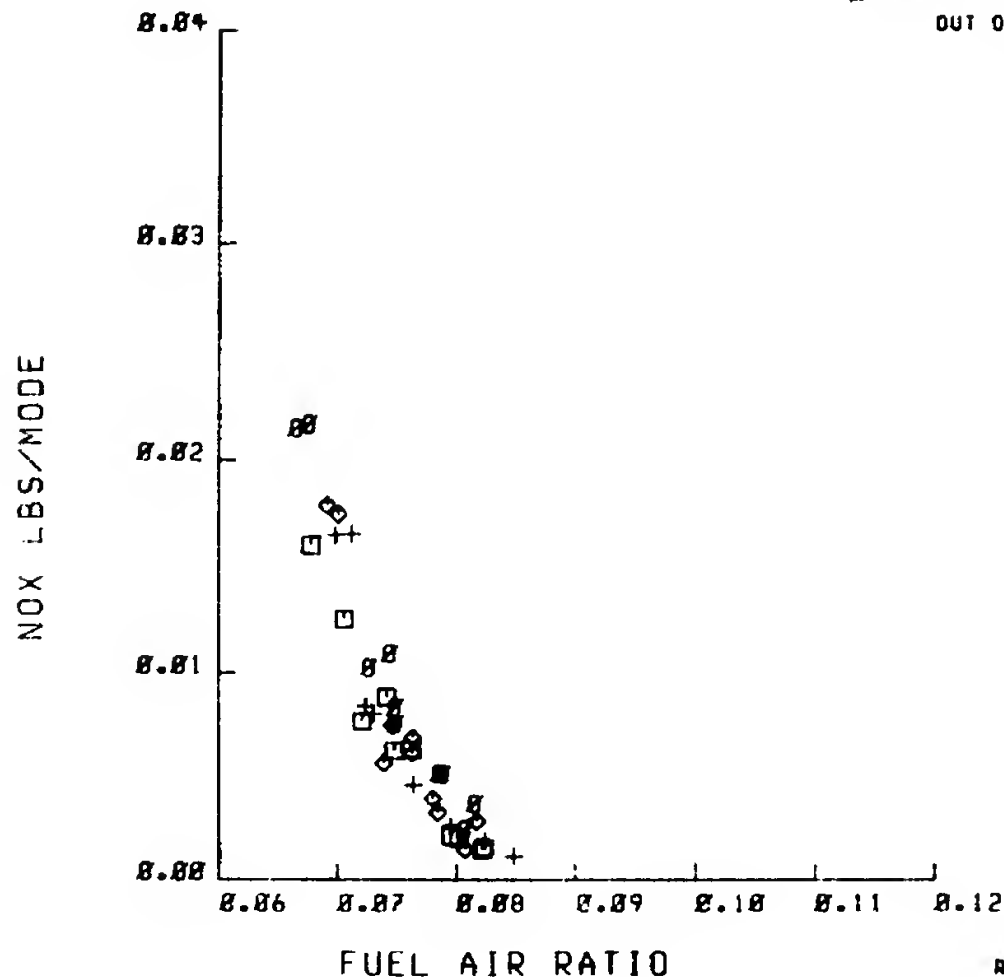
FIGURE 111

NASA LEAN-OUT DATA

TEMP. 50°F REL. HUM. 0, 30, 60, 80%

TAKE OFF EMISSIONS Ø-32Ø-DIAD

TEMP. DEG.F	REL. HUMIDITY			
	Ø	3Ø	6Ø	8Ø
	5Ø	Ø	◊	◻
	59	1	○	+
	ØØ	2	△	×
1ØØ	3	■	•	Z
OUT OF RANGE -				



TAKE-OFF
2431
2438
2445 Ø
2452
2458
2494
2501
2507 ◊
2514
2521
3639
3643
3652 ◻
3658
3664
3669
3674 +
3686
3692

TAKE-OFF
2435
2442 Ø
2448 Ø
2455
2461
2498
2504
2511 ◊
2517
2524
3640
3649
3655 ◻
3661
3667
3671
3680 +
3689 +
3695

ROC.2431

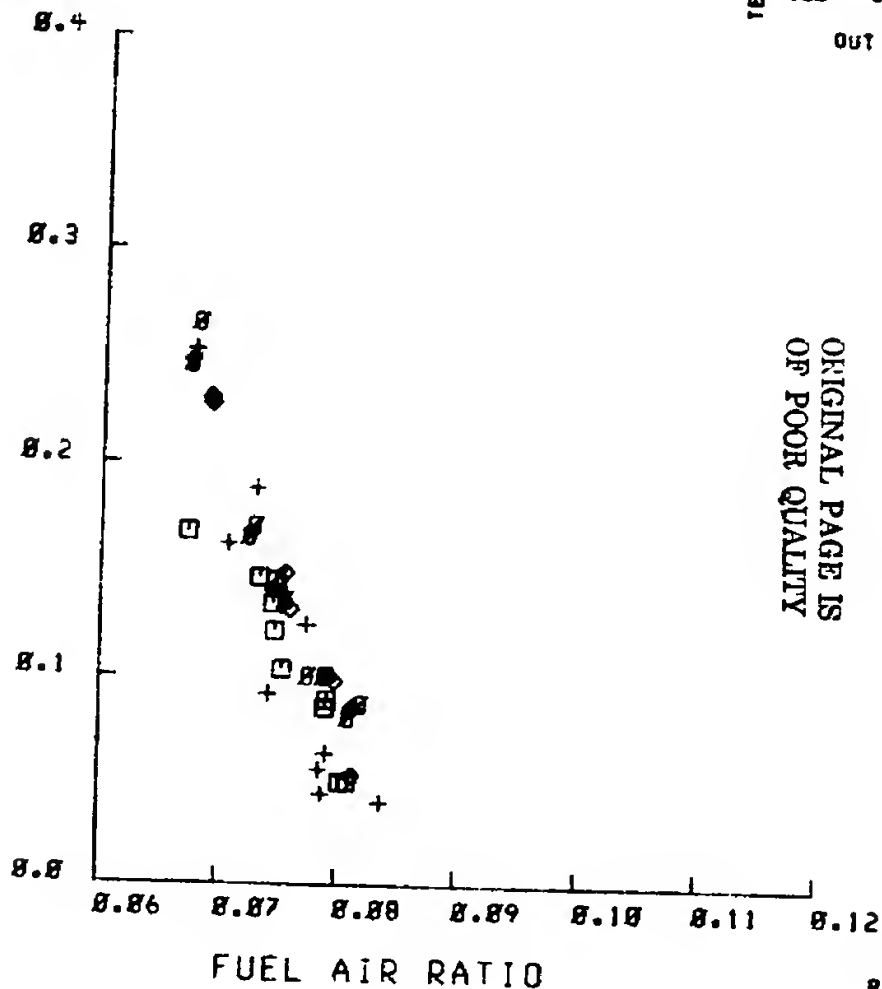
FIGURE 11^m

NASA LEAN-OUT DATA

TEMP. 50°F REL HUM. 0, 30, 60, 80%
CLIMB EMISSIONS B-32B-DIAD

TEMP. DEG.F	REL. HUMIDITY				
	0	30	60	80	
	50	1	2	3	+
	59	1	2	3	X
	68	2	3	4	Y
	100	3	4	5	Z
OUT OF RANGE -					

NOY LBS/MODE



CLIMB
2433
2439
2446 ϕ
2453
2459
2495
2502
2512 \diamond
2519
2525
3641
3647
3653 \square
3659
3665
3672
3678
3684 +
3690
3696

CLIMB
2436
2443
2449 ϕ
2456
2462
2499
2505
2515 \diamond
2522
3637
3644
3650 \square
3656
3662
3669
3675
3681 +
3687
3693

RDG.2433

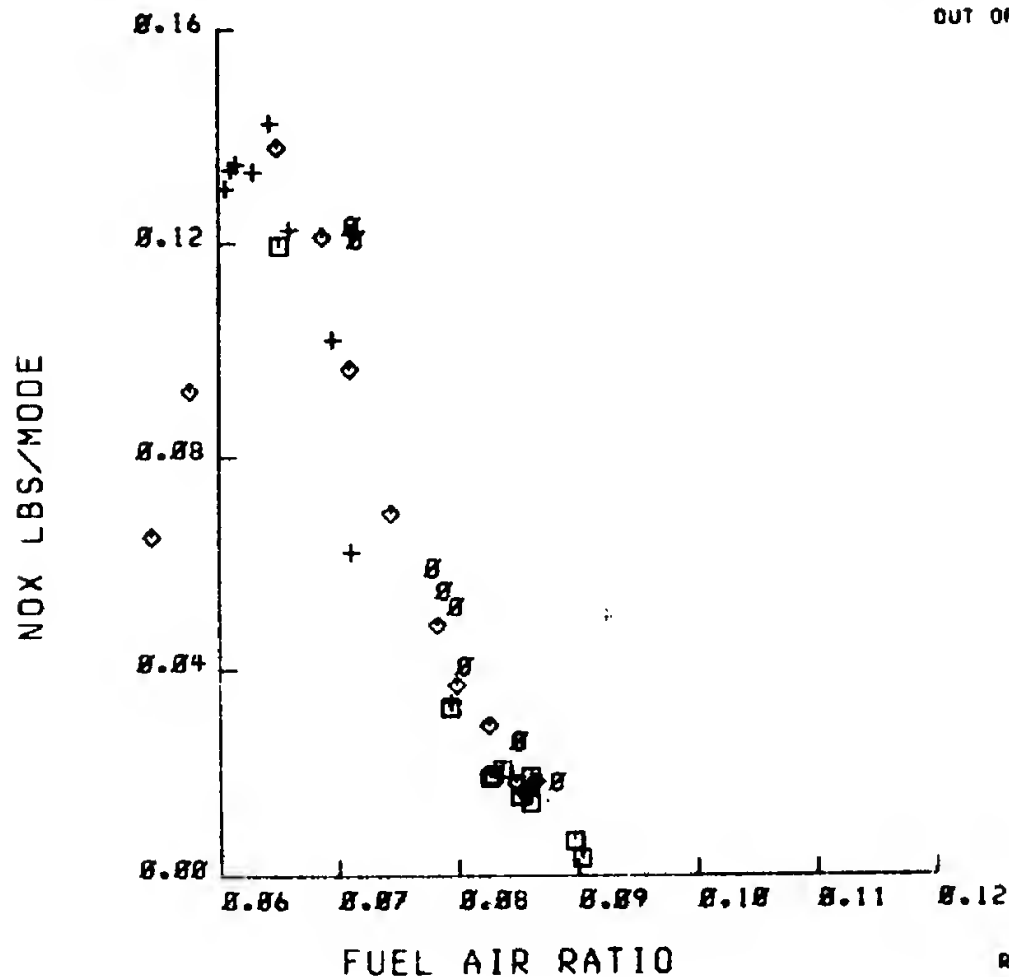
FIGURE 11n

NASA LEAN-OUT DATA

TEMP. 50°F REL HUM. 0, 30, 60, 80%

APPROACH EMISSIONS 0-320-DIAD

TEMP. DEG.F	REL. HUMIDITY			
	0	30	60	80
	50	0	□	+
	59	1	○	x
	68	2	△	y
	100	3	■	z
	OUT OF RANGE -			



APPROACH
2434
2441
2447
2454
2460
2496
3562
3564
3566
3568
3570
3638
3645
3651
3657
3663
3670
3676
3685
3691
3697

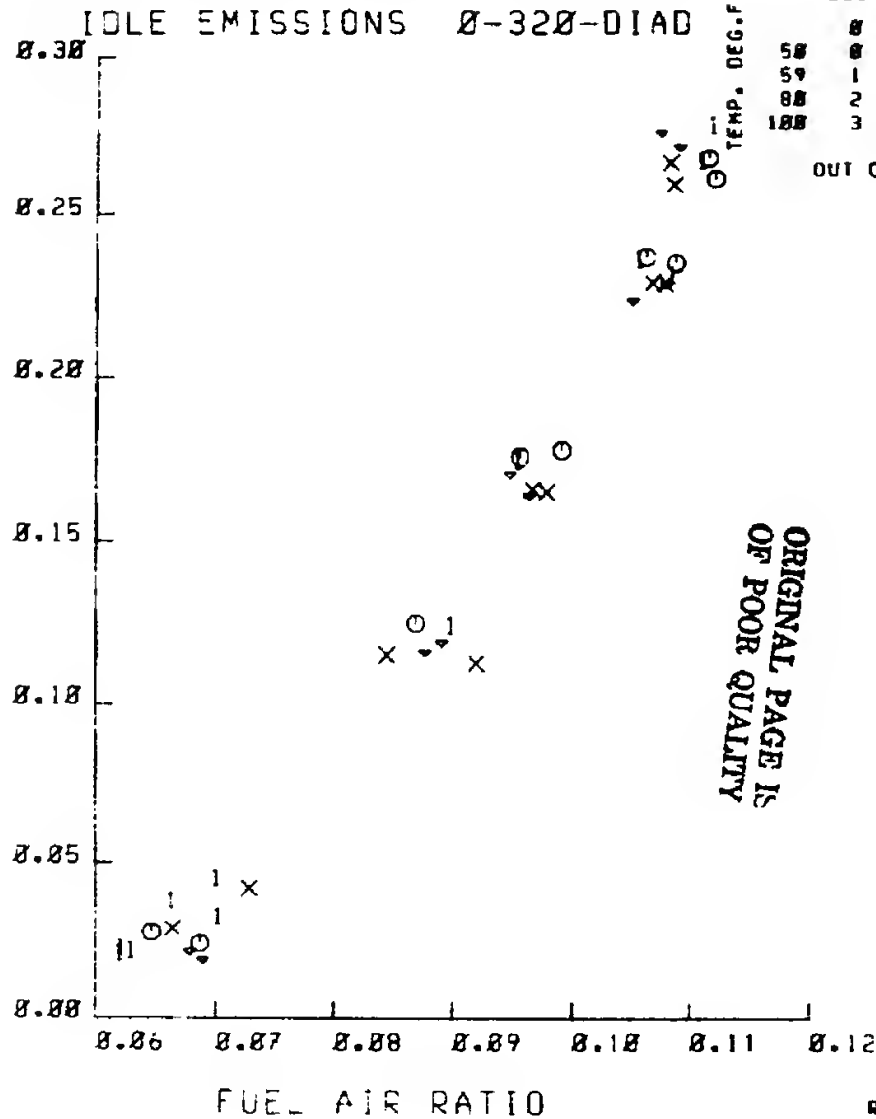
APPROACH
2437
2444
2450
2457
2453
3561
3563
3565
3567
3569
3571
3642
3648
3654
3660
3666
3673
3679
3688
3694

FIGURE 11°

NASA LEAN-OUT DATA

TEMP. 59°F REL HUM. 0, 30, 60, 80%

CO LBS/SGT 03



IDLE	IDLE
2703	2703
2708	2711
2712	3541
3542	3543
3545	3549
3550	3551
2757	2761
2765	2766
2768	2769
2773	2776
2777	2857
2860	2861
2866	2865
2868	2869
2872	2873
2876	2959
2963	2964
2968	2970
2973	2974
2978	2979
2982	

RDG.2703

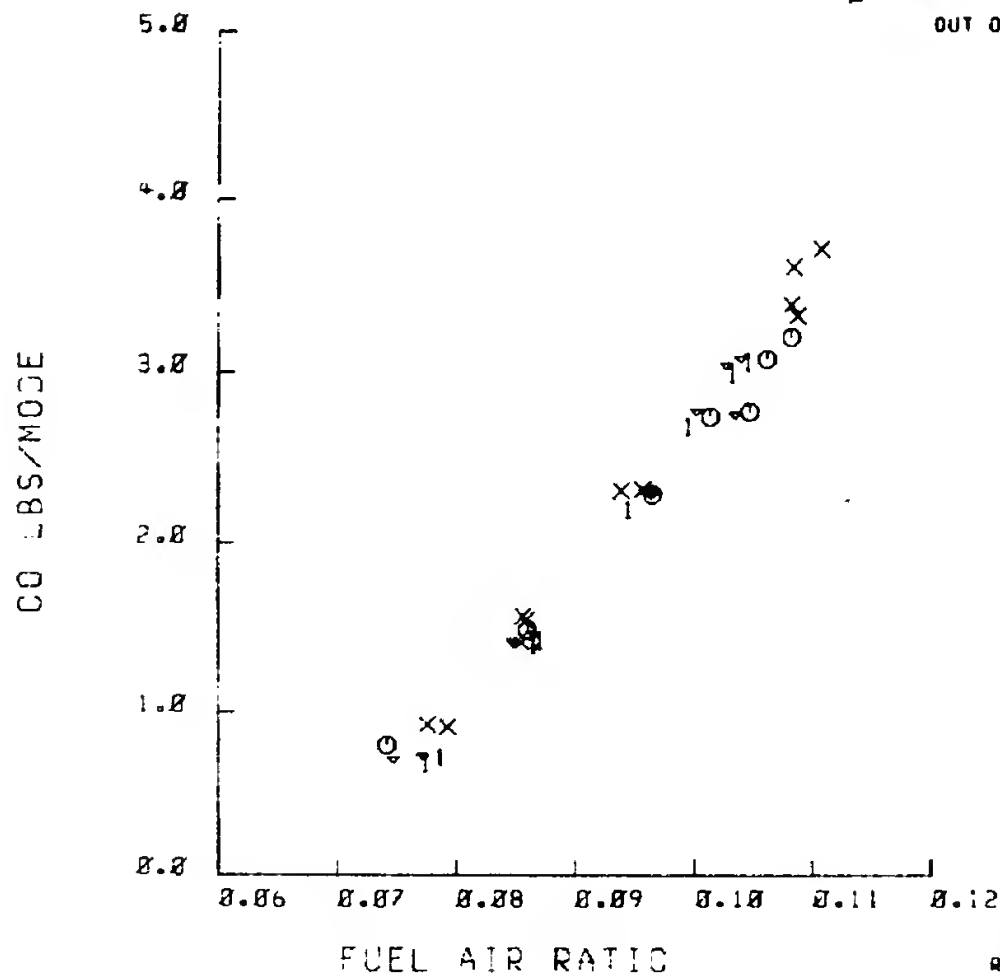
FIGURE 12a

NASA LEAN-OUT DATA

TEMP. 59°F REL HUM. 0, 30, 60, 80%

TAXI EMISSIONS 0-320-DIAD

TEMP. DEG.F	REL. HUMIDITY			
	0	30	60	80
	50	0	0	+
	59	1	0	X
	80	2	Δ	Y
100	3	Δ	Δ	Z
OUT OF RANGE -				



TAXI
2704
2710
2717
2721
2758
2763
2767
2771
2775
2859
2863
2867
2871
2875
2961
2967
2972
2976
2981

TAXI
2705
2714
2718
2722
2759
2754
2770
2774
2859
2862
2866
2870
2874
2950
2965
2971
2975
2980

FIGURE 12b

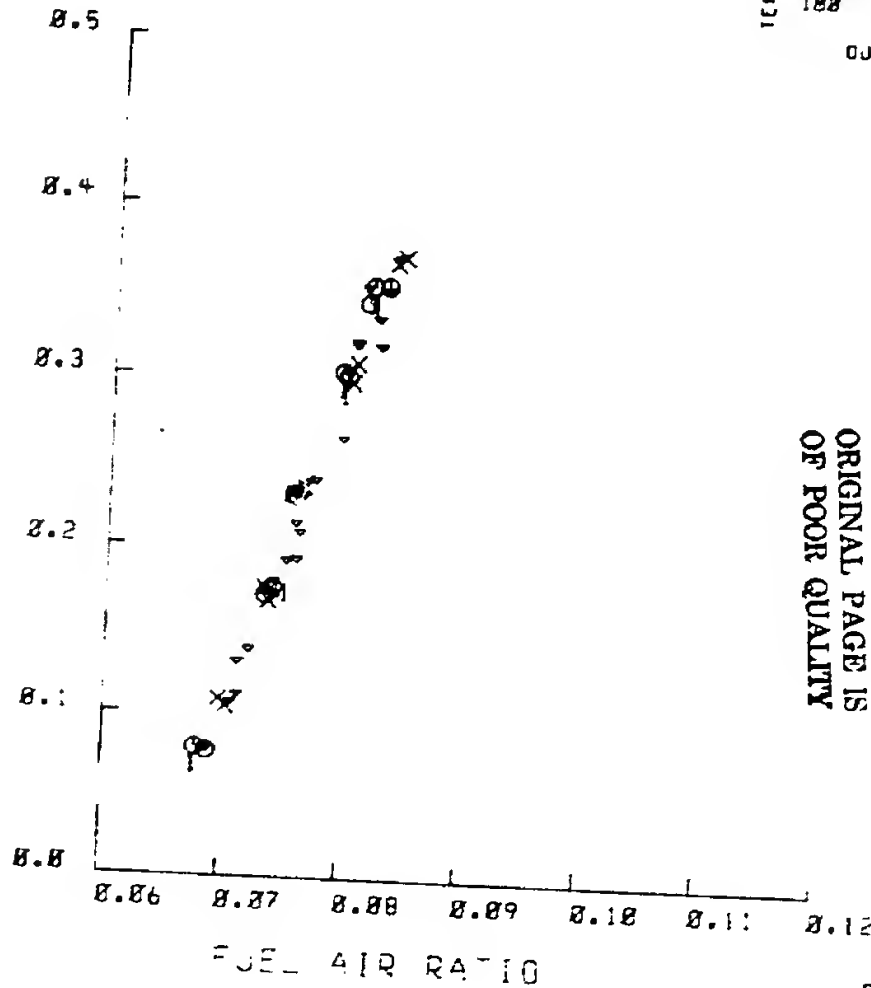
NASA LEAN-OUT DATA

TEMP. 59°F REL HUM. 0, 30, 60, 80%
TAKE OFF EMISSIONS Ø-32Ø-DIAD

TEMP. DEG. F	REL. HUMIDITY			
	Ø	3Ø	6Ø	ØØ
	5Ø	Ø	Ø	+
	59	1	Ø	X
	ØØ	2	Δ	Y
1ØØ	3	■	•	Z

OUT OF RANGE ~

CO LRS/MODE



TAKE-OFF	TAKE-OFF
2774	2729
2731	2735
2738	2741
2744	2747
2752	2753
2778	2781
2784	2785
2788	2791
2794	2797
2800	2803
2806	2812
2819	2823
2835	2838
2841	2844
2848	2850
2877	2880
2883	2884
2890	2893
2896	2899
2902	2905
2915	2916
2919	2922
2925	2928
2931	2935
2941	2944

FIG. 2724

FIGURE 12c

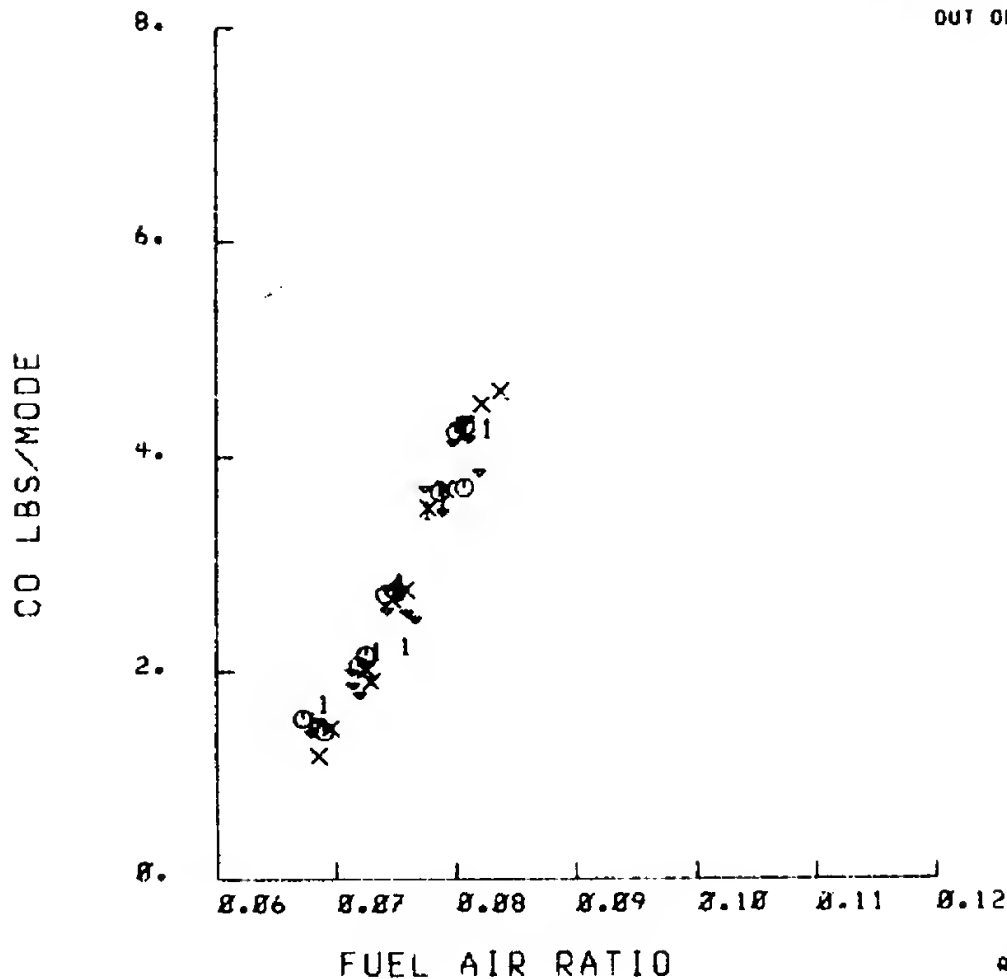
NASA LEAN-OUT DATA

TEMP. 59°F REL HUM. 0, 30, 60, 80%

CLIMB EMISSIONS Ø-32Ø-DIAD

TEMP. DEG.F	REL.HUMIDITY			
	Ø	3Ø	6Ø	8Ø
5Ø	Ø	Ø	Ø	+
59	1	Ø	Ø	X
8Ø	2	Δ	Ø	Y
18Ø	3	■	Δ	Z

OUT OF RANGE -



CLIMB	CLIMB
2729	2725
2736	2732
2742	2739
2748	2745
2754	2751
2782	2779
2789	2786
2795	2792
2801	2798
2817	2804
2813	2815
2824	2820
2839	2836
2845	2842
2851	2849
3553	3552
3555	3554
3557	3556
2916	2913
2923	2920
2929	2926
2936	2932
2945	2942

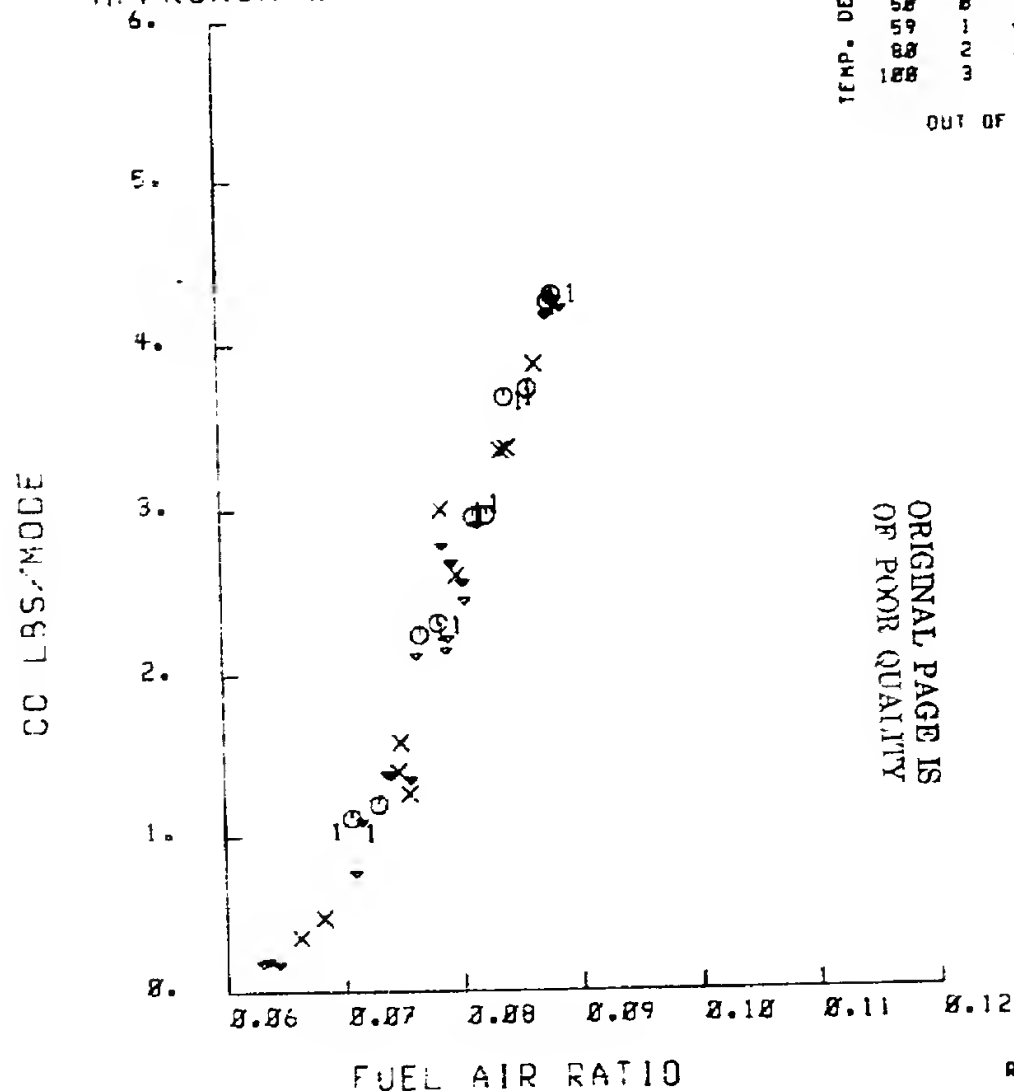
RDG.2725

FIGURE 12a

NASA LEAN-OUT DATA

TEMP. 59°F REL HUM. 0, 30, 60, 80%

APPROACH EMISSIONS Ø-32Ø-DIAD



ORIGINAL PAGE IS
OF POOR QUALITY

APPROACH	APPROACH
2726	2730
2733	2737
2740	2743
2746	2749
2752	2755
2760	2763
2767	2790
2793	2796
2799	2802
2805	2808
2811	2814
2822	2825
2837	2840
2843	2846
2847	2852
2879	2882
2885	2889
2892	2895
2898	2901
2904	2908
2914	2917
2921	2924
2927	2930
2934	2940
2943	2946

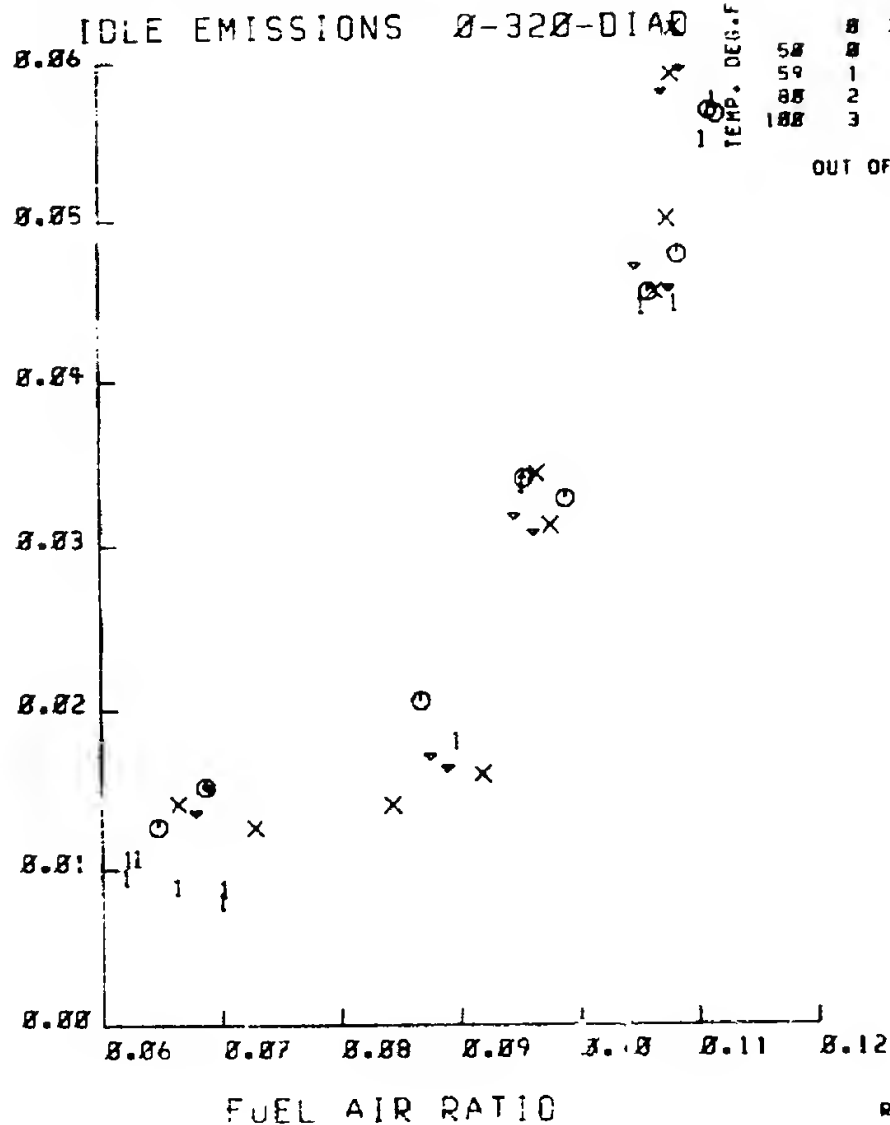
DOC. 2726

FIGURE 12e

NASA LEAN-OUT DATA

TEMP. 59°F REL HUM. 0, 30, 60, 80%

HC LBS/MODE



IDLE	IDLE
2703	2705
2708	2711
2712	3541
3542	3543
3545	3549
3550	3551
2757	2761
2765	2766
2768	2769
2773	2776
2777	2857
2860	2861
2864	2865
2868	2869
2872	2873
2876	2959
2963	2964
2968	2970
2973	2974
2978	2979
2982	

FIGURE 12f

NASA LEAN-OUT DATA

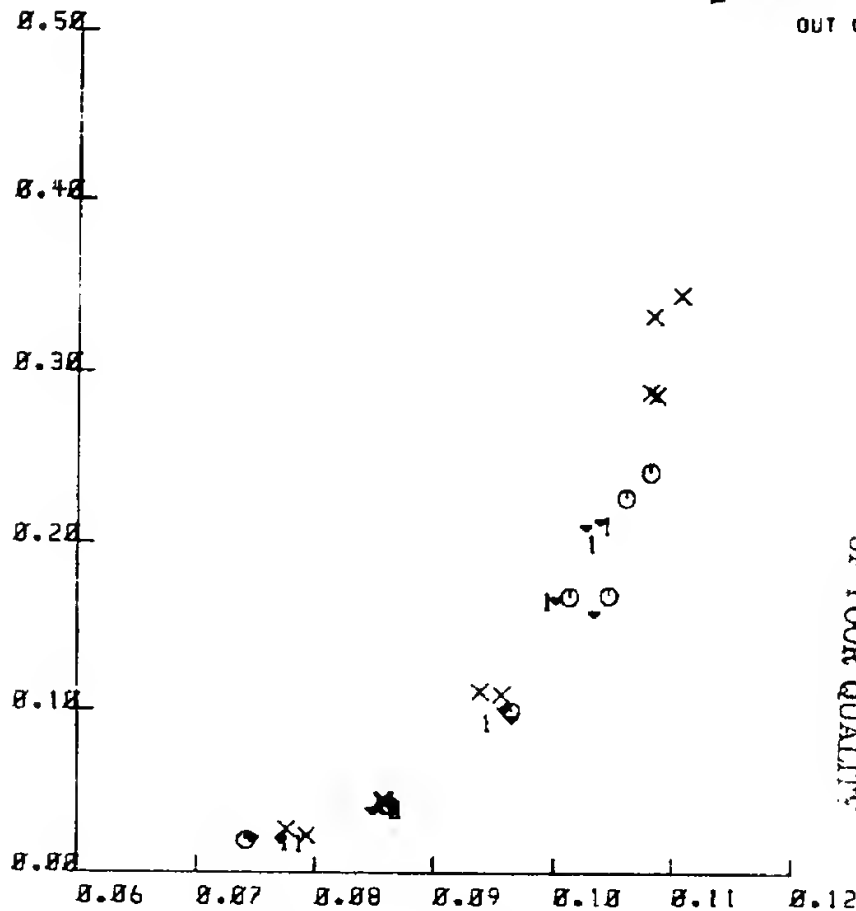
TEMP. 59°F REL HUM. 0, 30, 60, 80%

TAXI EMISSIONS Ø-32Ø-DIAD

TEMP. DEG.F	REL.HUMIDITY			
	Ø	3Ø	6Ø	8Ø
	Ø	Ø	Ø	+
	1	Ø	Ø	X
	2	Δ	Ø	Y
18Ø	3	✱	Δ	Z

OUT OF RANGE -

HC LBS/MODE



ORIGINAL PAGE IS
OF POOR QUALITY

TAXI
2704
2710 I
2717
2721
2758
2763
2767 Ø
2771
2775
2859
2863
2867 ▽
2871
2875
2961
2967
2972 X
2976
2981

TAXI
2705
2714 I
2718
2722
2759
2764
2770 Ø
2774
2858
2862
2866 ▽
2870
2874
2955
2965
2971 X
2975
2980

FUEL AIR RATIO

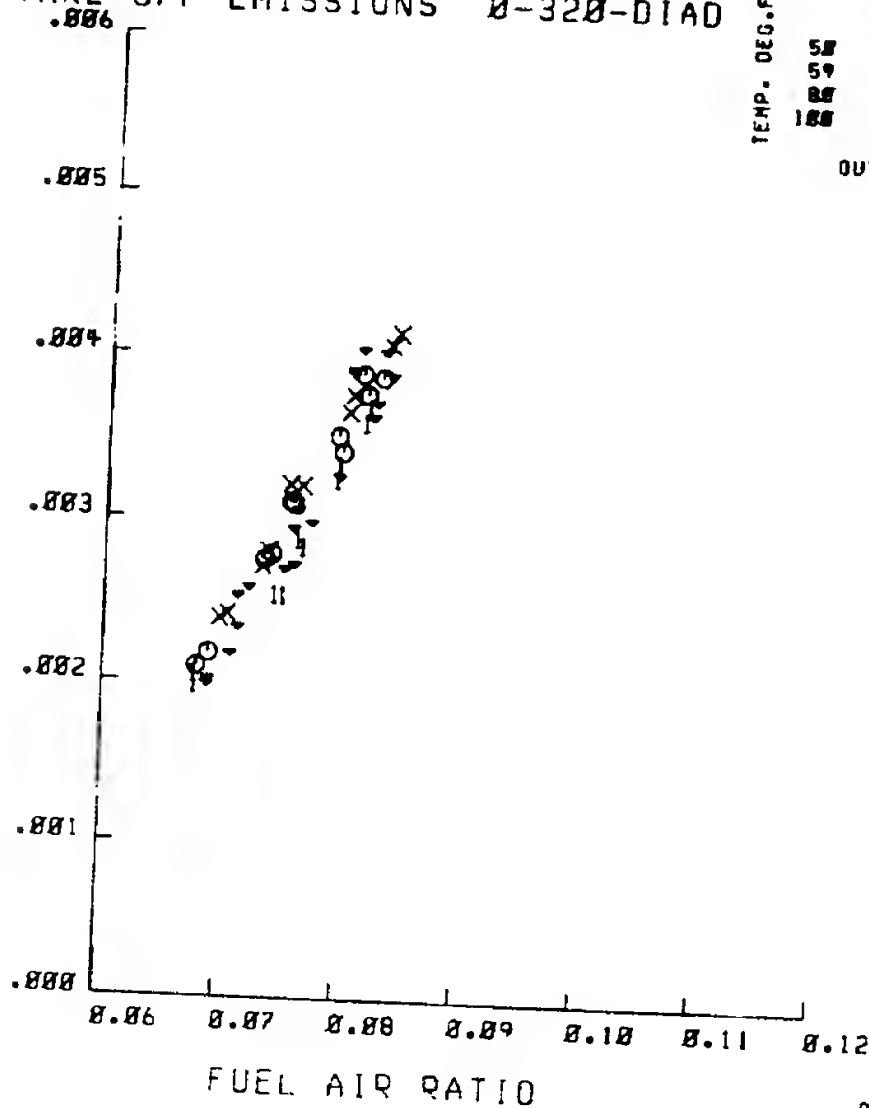
RDG.27Ø4

FIGURE 12g

NASA LEAN-OUT DATA

TEMP. 590F REL HUM. 0, 30, 60, 80%
TAKE OFF EMISSIONS Ø-32Ø-DIAD

HC LBS/MODE



REL. HUMIDITY
59 8 30 60 80
59 8 0 0 0 +
80 1 0 0 0 X
80 2 0 0 0 Y
100 3 0 0 0 Z
OUT OF RANGE -

TAKE-OFF	TAKE-OFF
2724	2728
2731	2735
2738	2741
2744	2747
2750	2753
2778	2781
2784	2785
2788	2791
2794	2797
2800	2803
2806	2812
2819	2823
2835	2838
2841	2844
2848	2850
2877	2880
2883	2886
2890	2893
2896	2899
2902	2905
2915	2918
2919	2922
2925	2928
2931	2935
2941	2944

ROC. 2724

FIGURE 12h

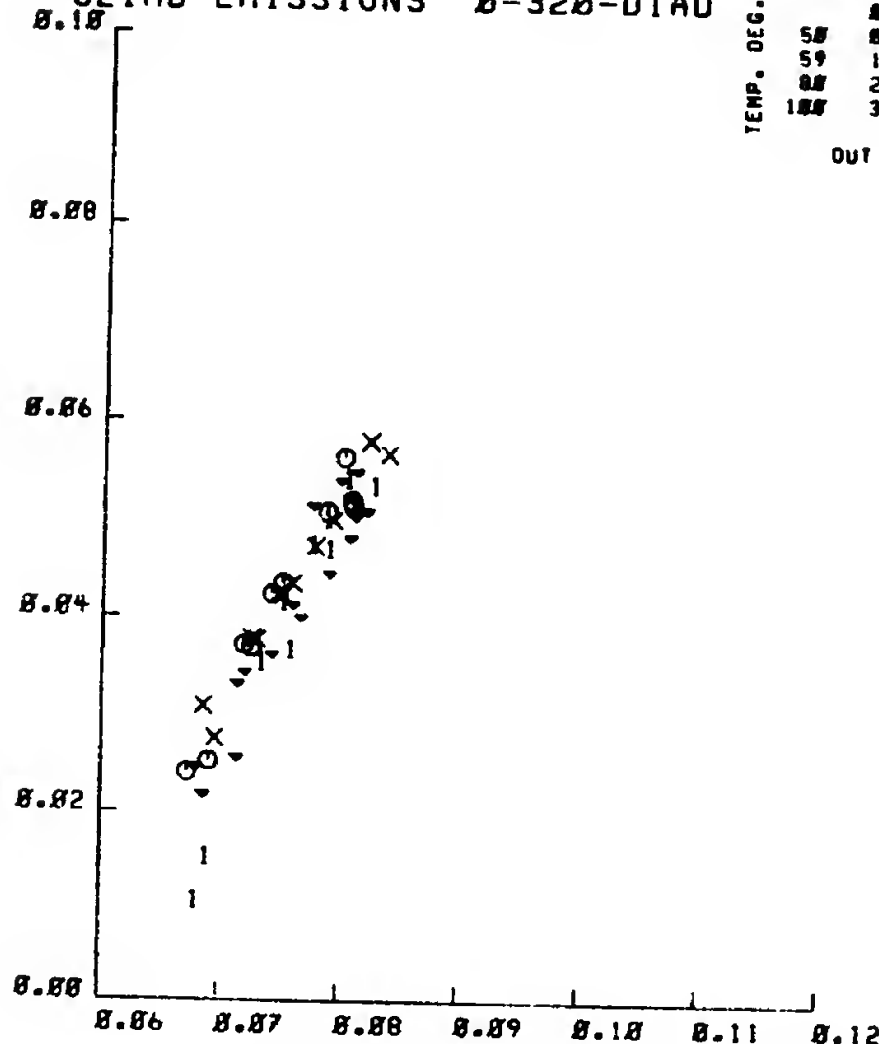
NASA LEAN-OUT DATA

TEMP. 59°F REL HUM. 0, 30, 60, 80%

CLIMB EMISSIONS 8-328-DIAD

TEMP. DEG. F	REL. HUMIDITY			
	0	30	60	80
	58	8	0	+
	59	1	0	X
	88	2	Δ	Y
188	3	■	•	Z
OUT OF RANGE -				

HC LBS/MODE



ORIGINAL PAGE IS
OF POOR QUALITY

CLIMB
2725
2732
2739
2745
2751
2779
2786
2792
2798
2804
2810
2820
2836
2842
2849
3552
3554
3556
2913
2920
2926
2932
2942

CLIMB
2729
2736
2742
2748
2754
2782
2789
2795
2801
2807
2813
2824
2839
2845
2851
3553
3555
3557
2916
2923
2929
2936
2945

RDG. 2725

FIGURE 12i

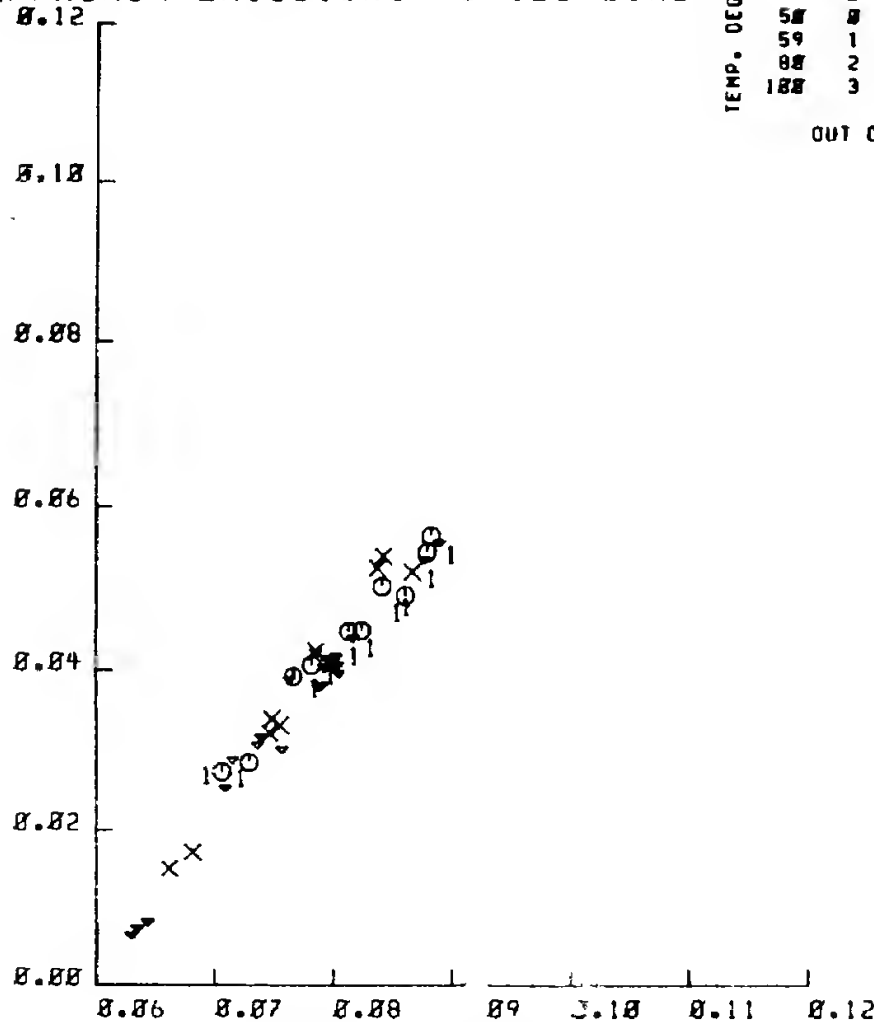
NASA LEAN-OUT DATA

TEMP. 59°F REL HUM. 0, 30, 60, 80%

APPROACH EMISSIONS Ø-32Ø-DIAD

TEMP. DEG.F	REL.HUMIDITY			
	Ø	3Ø	6Ø	8Ø
	5Ø	Ø	◊	◻
	59	1	○	×
	88	2	△	•
188	3	✖	▲	Ζ
	OUT OF RANGE -			

HC LBS/MODE



FUEL AIR RATIO

RDG.2726

APPROACH	APPROACH
2726	2730
2733	2737
2740	2743
2746	2749
2752	2755
2780	2783
2787	2790
2793	2796
2799	2802
2805	2808
2811	2814
2822	2825
2837	2840
2843	2846
2847	2852
2870	2882
2885	2889
2892	2895
2898	2901
2904	2908
2914	2917
2921	2924
2927	2930
2934	2940
2943	2946

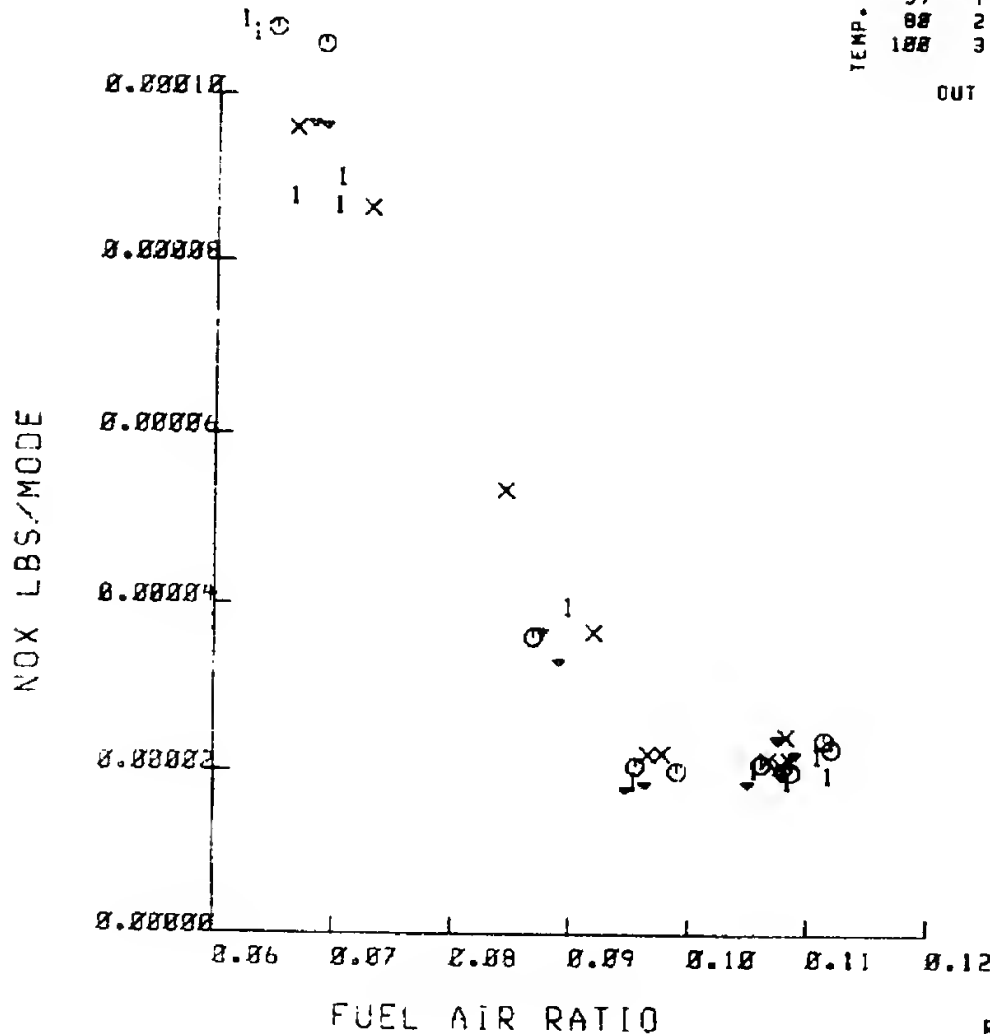
FIGURE 12j

NASA LEAN-OUT DATA

TEMP. 59°F REL. HUM. 0, 30, 60, 80%

IDLE EMISSIONS Ø-325-DIAD

TEMP. DEG.F	REL. HUMIDITY			
	Ø	3Ø	6Ø	8Ø
	5Ø	Ø	Ø	+
	59	1	Ø	X
	8Ø	2	Δ	Y
1ØØ	3	*	Δ	Z
OUT OF RANGE -				



ORIGINAL PAGE IS
A GOOD QUALITY

IDLE	IDLE
2703	2705
2708	2711
2712	3541
3542	3543
3545	3549
3550	3551
2757	2761
2765	2766
2760	2769
2773	2776
2777	2857
2860	2861
2864	2865
2868	2869
2872	2873
2876	2959
2963	2964
2968	2970
2973	2974
2978	2979
2982	

FIGURE 12^k

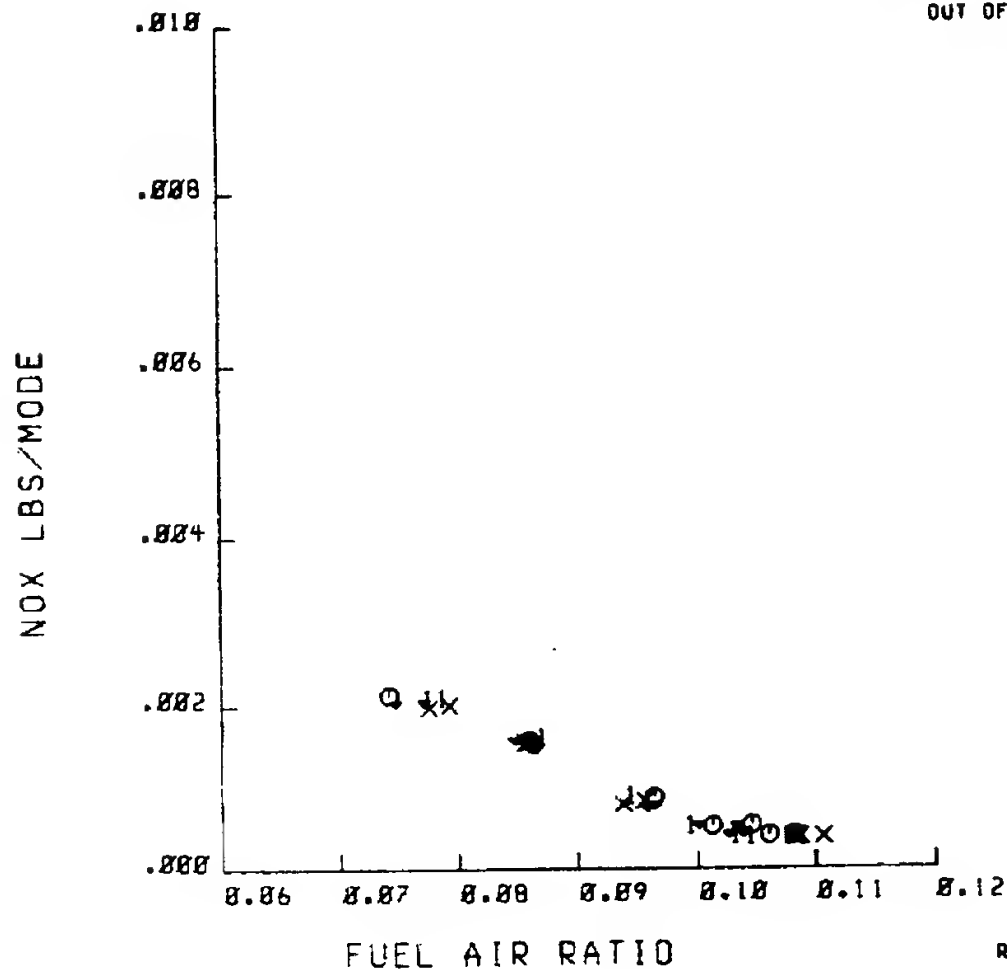
ROC-27Ø3

NASA LEAN-OUT DATA

TEMP 59°F REL HUM. 0, 30, 60, 80%

TAXI EMISSIONS Ø-32Ø-DIAD

TEMP. DEG.F	REL.HUMIDITY			
	Ø	3Ø	6Ø	8Ø
	Ø	Ø	Ø	+
	1	Ø	Ø	X
	2	Δ	•	Y
18Ø	3	✱	Δ	Z
OUT OF RANGE -				



TAXI	TAXI
2704	2705
2710 J	2714 J
2717	2718
2721	2722
2758	2759
2763	2764
2767 Ø	2770 Ø
2771	2774
2775	2858
2859	2862
2863	2866 ▽
2867 ▽	2870
2871	2874
2875	2950
2961	2965
2957	2971 X
2972 X	2975
2976	2980
2981	

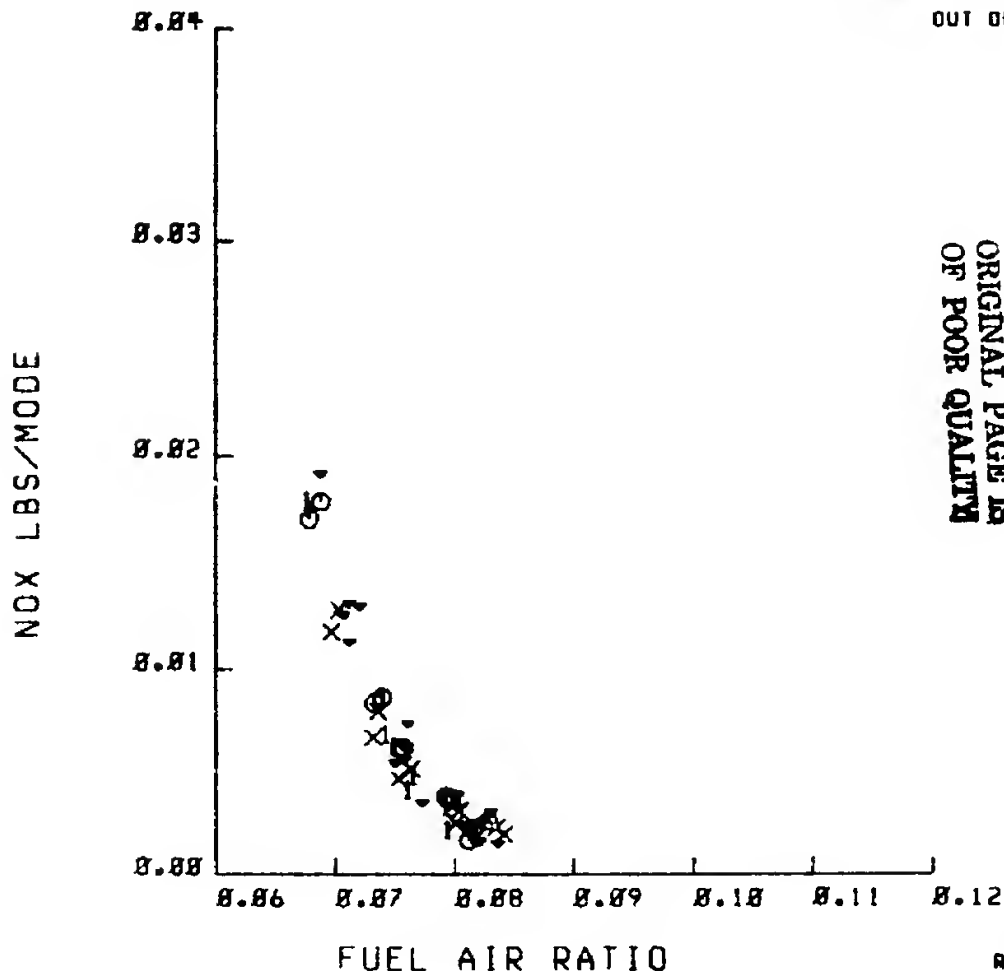
FIGURE 12¹

NASA LEAN-OUT DATA

TEMP. 59°F REL HUM. 0, 30, 60, 80%

TAKE OFF EMISSIONS Ø-32Ø-DIAD

TEMP. DEG. F	REL. HUMIDITY				
	Ø	30	60	80	
	59	Ø	Ø	Ø	+
	59	1	Ø	Ø	X
	80	2	Δ	Ø	Y
	100	3	✱	Ø	Z
OUT OF RANGE -					



TAKE-OFF	TAKE-OFF
2724	2729
2731	2735
2738	2741
2744	2747
2750	2753
2778	2781
2784	2785
2788	2791
2794	2797
2800	2803
2806	2812
2819	2823
2835	2838
2841	2844
2848	2850
2877	2880
2883	2886
2890	2893
2896	2899
2902	2905
2915	2918
2919	2922
2925	2928
2931	2935
2941	2944

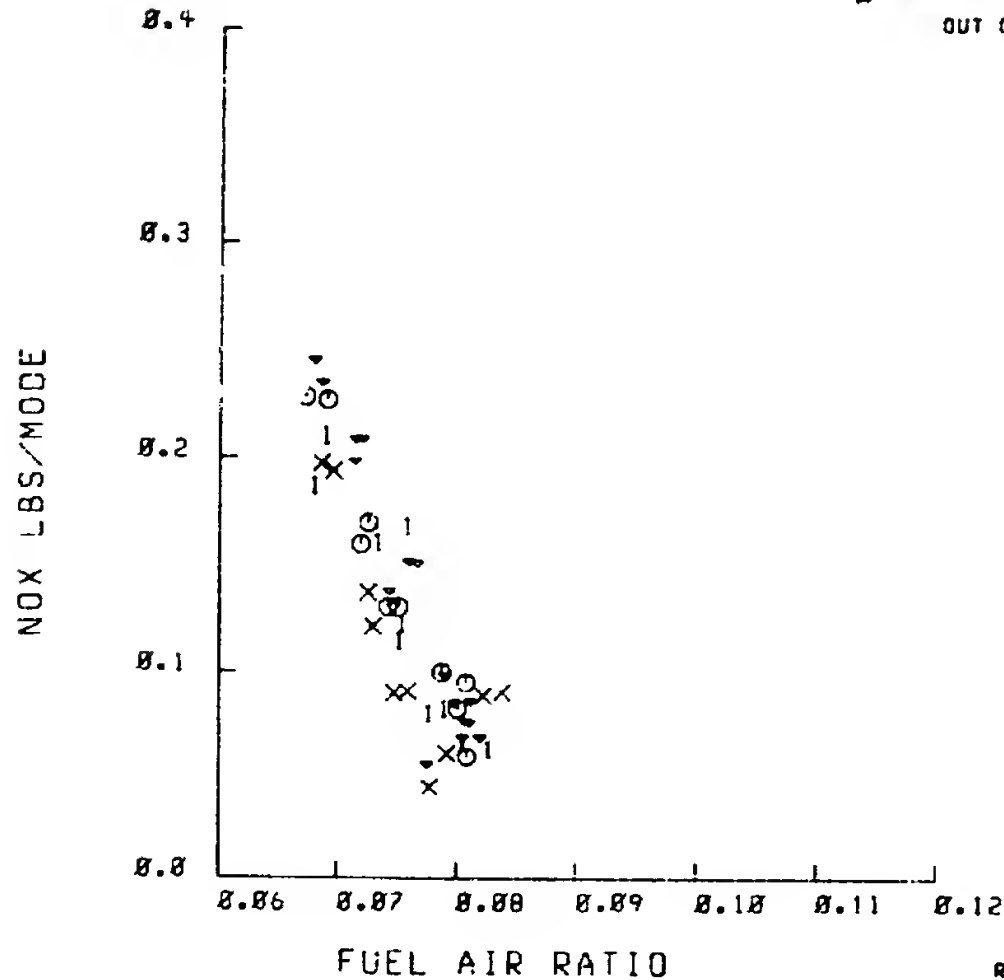
RDG.2724

FIGURE 12_m

NASA LEAN-OUT DATA

TEMP. 59°F REL HUM. 0, 30, 60, 80%
CLIMB EMISSIONS Ø-32Ø-DIAD

TEMP. DEG.F	REL.HUMIDITY			
	Ø	3Ø	6Ø	ØØ
	5Ø	Ø	◊	◻
	59	1	○	•
	ØØ	2	△	•
1ØØ	3	■	•	•
OUT OF RANGE -				



CLIMB	CLIMB
2725	2729
2732	2736
2739	2742
2745	2748
2751	2754
2779	2782
2786	2789
2792	2795
2798	2801
2804	2807
2810	2813
2820	2824
2836	2839
2842	2845
2849	2851
3552	3553
3554	3555
3556	3557
2913	2916
2920	2923
2926	2929
2932	2936
2942	2945

FIGURE 12n

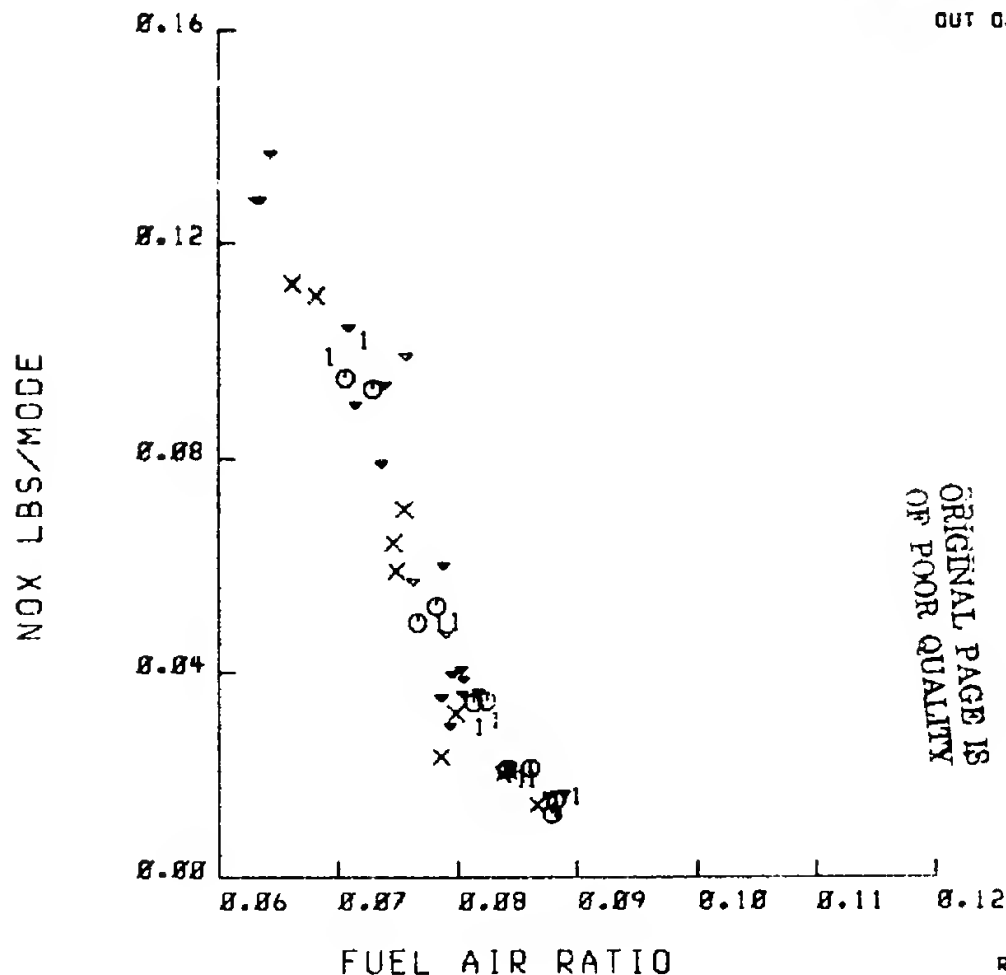
ROC.2725

NASA LEAN-OUT DATA

TEMP. 59°F REL HUM. 0, 30, 60, 80%

APPROACH EMISSIONS Ø-32Ø-DIAD

TEMP. DEG.F	REL.HUMIDITY			
	Ø	3Ø	6Ø	ØØ
	5Ø	Ø	Ø	+
	59	1	Ø	X
	8Ø	2	Δ	Y
1ØØ	3	⋈	Δ	Z
OUT OF RANGE -				



APPROACH	APPROACH
2726	2730
2733	2737
2740	2743
2746	2749
2752	2755
2780	2793
2787	2790
2793	2796
2799	2802
2805	2808
2811	2814
2822	2825
2837	2840
2843	2846
2847	2852
2879	2882
2885	2889
2892	2895
2898	2901
2904	2908
2914	2917
2921	2924
2927	2930
2934	2940
2943	2946

RDG.2726

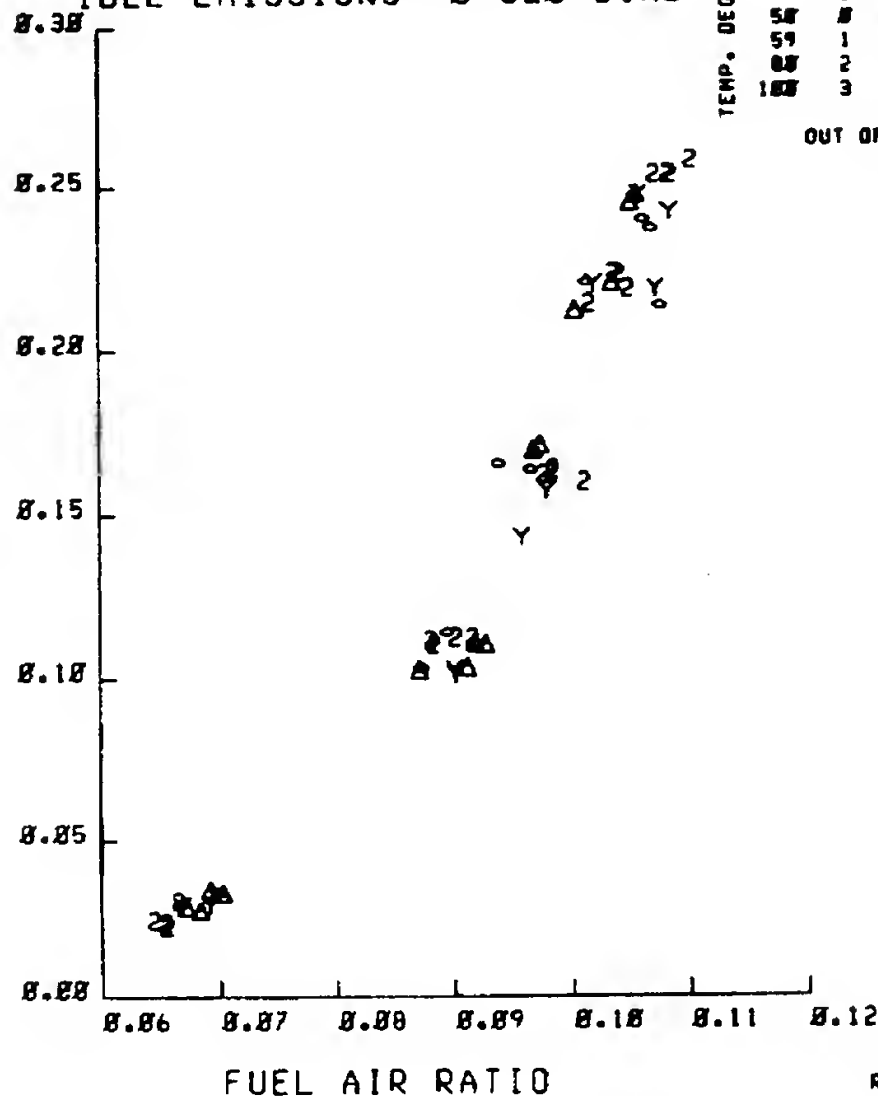
FIGURE 12°

NASA LEAN-OUT DATA

TEMP. 80°F REL HUM. 0, 30, 60, 80%

IDLE EMISSIONS B-320-DIAD

CO LBS/MODE



IDLE	
3293	
3296	
3301	
3305	
3309	
3313	2
3320	
3322	
3328	
3332	
3345	
3348	
3350	
3356	△
3372	
3406	
3411	
3419	
3422	
3431	○
3433	
3439	
3446	
3451	
3453	Y
3458	
3463	

IDLE	
3295	
3300	
3304	
3308	
3310	2
3314	
3321	
3326	
3331	
3335	
3346	
3349	
3351	
3358	△
3374	
3410	
3414	
3420	
3425	
3432	○
3437	
3442	
3447	
3452	
3457	Y
3462	
3466	

RDG.3293

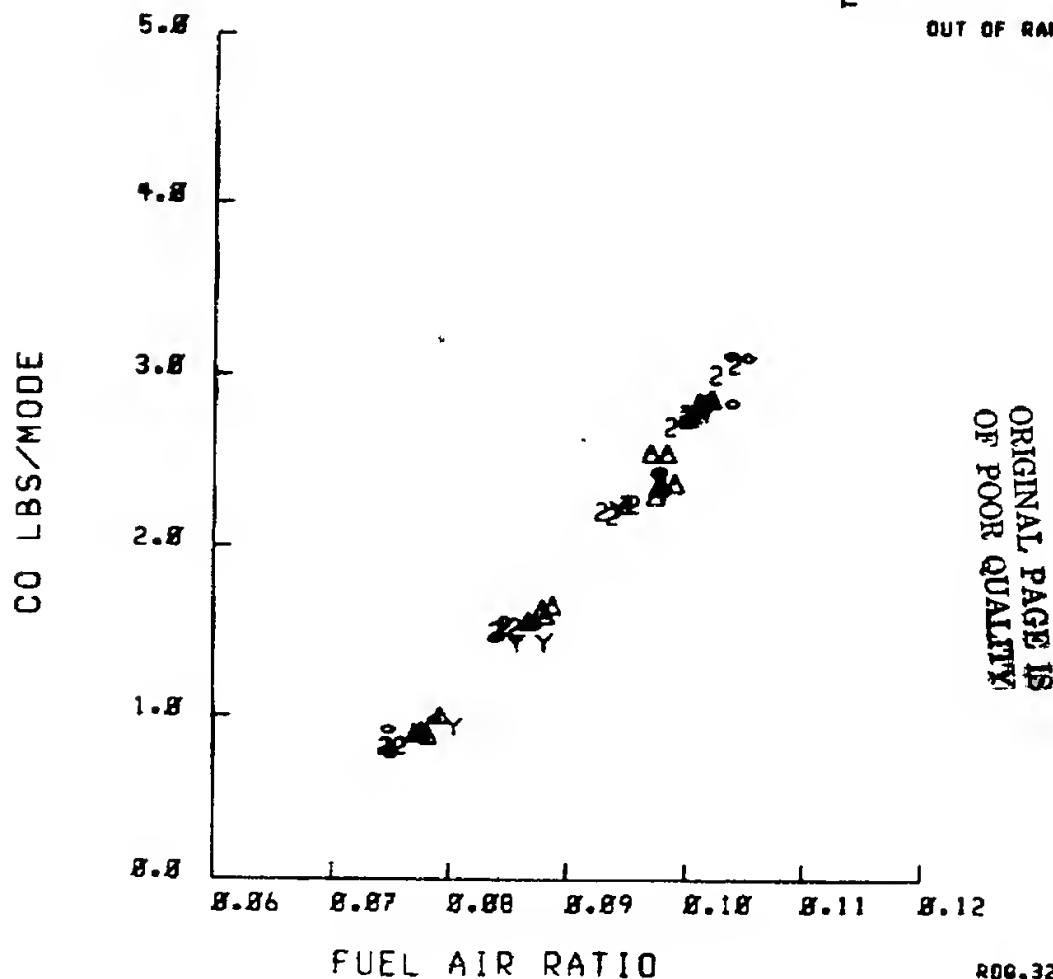
FIGURE 13a

NASA LEAN-OUT DATA

TEMP. 80°F REL. HUM. 0, 30, 60, 80%

TAXI EMISSIONS B-320-DIAD

TEMP. DEG.F	REL. HUMIDITY			
	0	30	60	80
	○	◇	□	+
	1	○	◇	X
	2	△	◇	Y
100	3	*	△	Z
OUT OF RANGE -				



TAXI		TAXI	
3291		3292	
3297		3298	
3302		3303	
3306		3307	
3311		3312	2
3315	2	3316	
3319		3323	
3324		3327	
3329		3330	
3333		3334	
3342		3343	
3344		3347	
3352		3353	
3354	△	3355	
3361		3362	△
3363		3364	
3407		3408	
3412		3413	
3417		3421	
3423		3424	
3427	○	3429	○
3434		3435	
3440		3441	
3444		3445	
3449		3450	
3455	Y	3456	Y
3459		3460	
3464		3465	

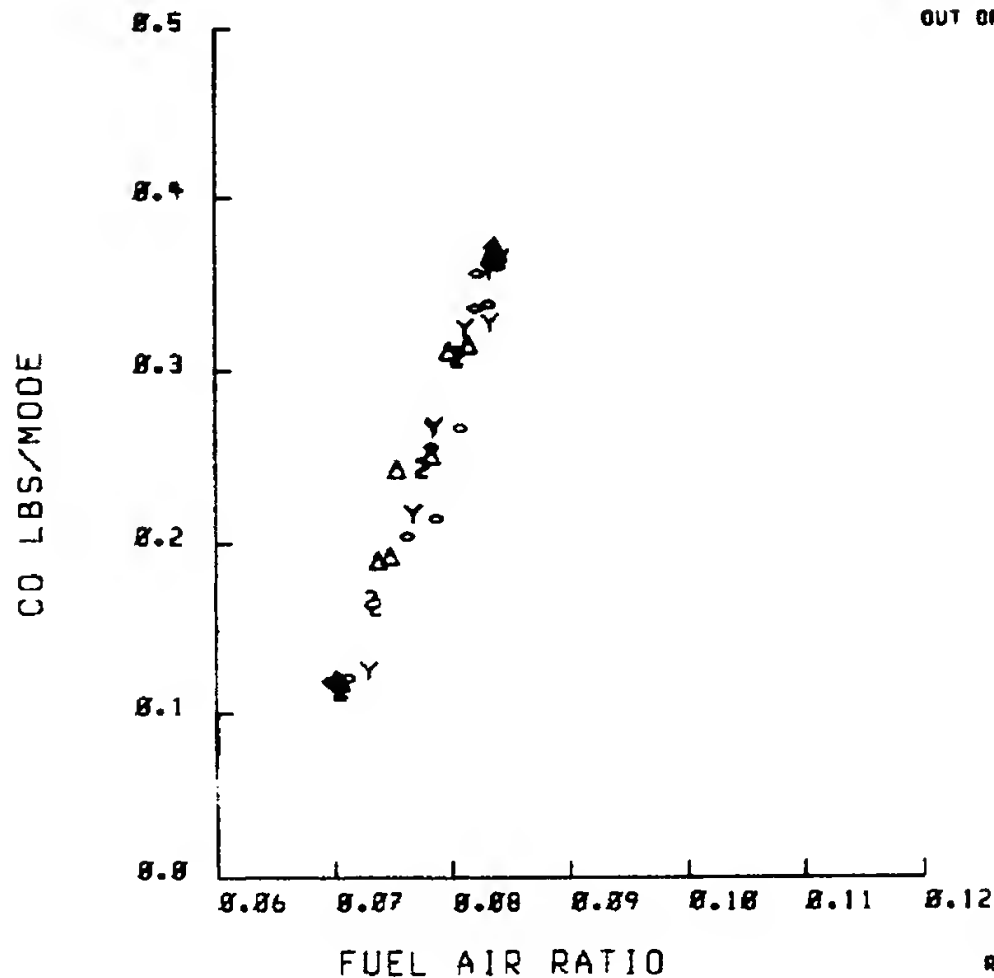
FIGURE 13b

NASA LEAN-OUT DATA

TEMP. 80°F REL HUM. 0, 30, 60, 80%

TAKE OFF EMISSIONS Ø-32Ø-DIAD

TEMP. DEG.F	REL. HUMIDITY			
	Ø	3Ø	6Ø	8Ø
	Ø	Ø	Ø	+
	1	Ø	Ø	X
	2	Δ	Ø	Y
18Ø	3	R	Ø	Z
OUT OF RANGE -				



TAKE-OFF
 3260
 3266
 3272 2
 3278
 3284
 3376
 3382
 3388 Δ
 3394
 3400
 3497
 3503
 3509 Ø
 3515
 3521
 3467
 3473
 3479 Y
 3485
 3491

TAKE-OFF
 3263
 3269
 3275 2
 3281
 3287
 3379
 3385
 3391 Δ
 3397
 3403
 3500
 3506
 3512 Ø
 3518
 3524
 3470
 3476 Y
 3482
 3488

FIGURE 13c

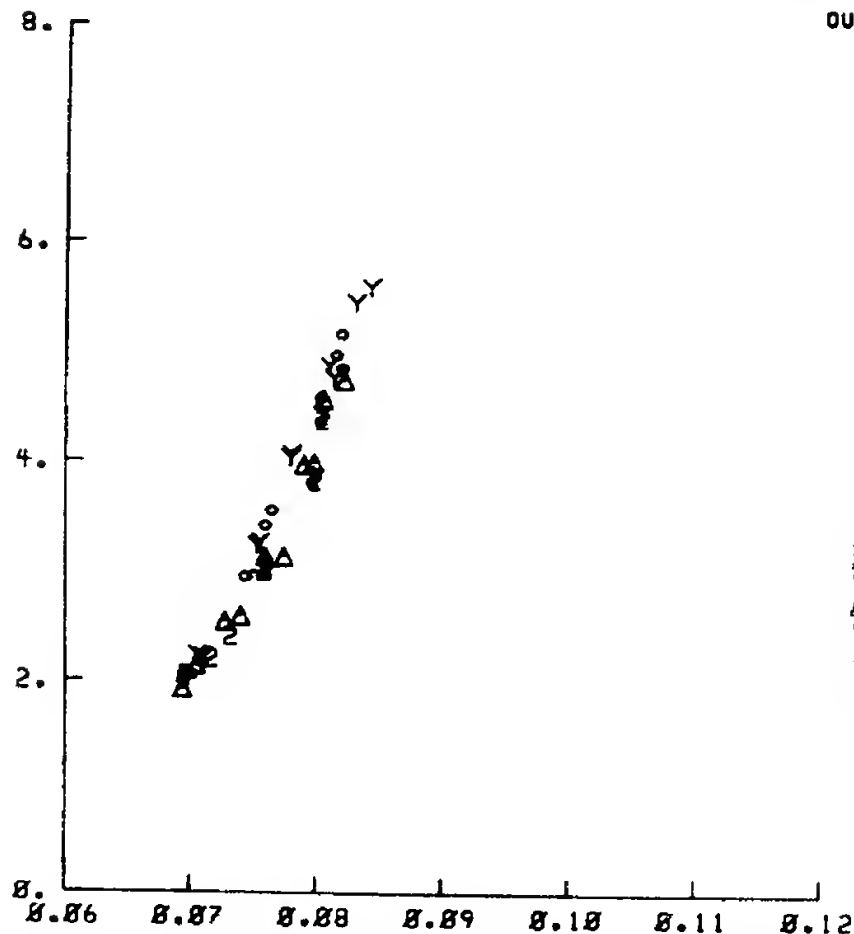
NASA LEAN-OUT DATA

TEMP. 80°F REL HUM. 0, 30, 60, 80%

CLIMB EMISSIONS 8-328-DIAD

TEMP. DEG.F	REL. HUMIDITY			
	58	59	60	61
	58	59	60	61
	58	59	60	61
	58	59	60	61
OUT OF RANGE	-	-	-	-

CO LBS/MODE



ORIGINAL PAGE IS
OF LOWER QUALITY

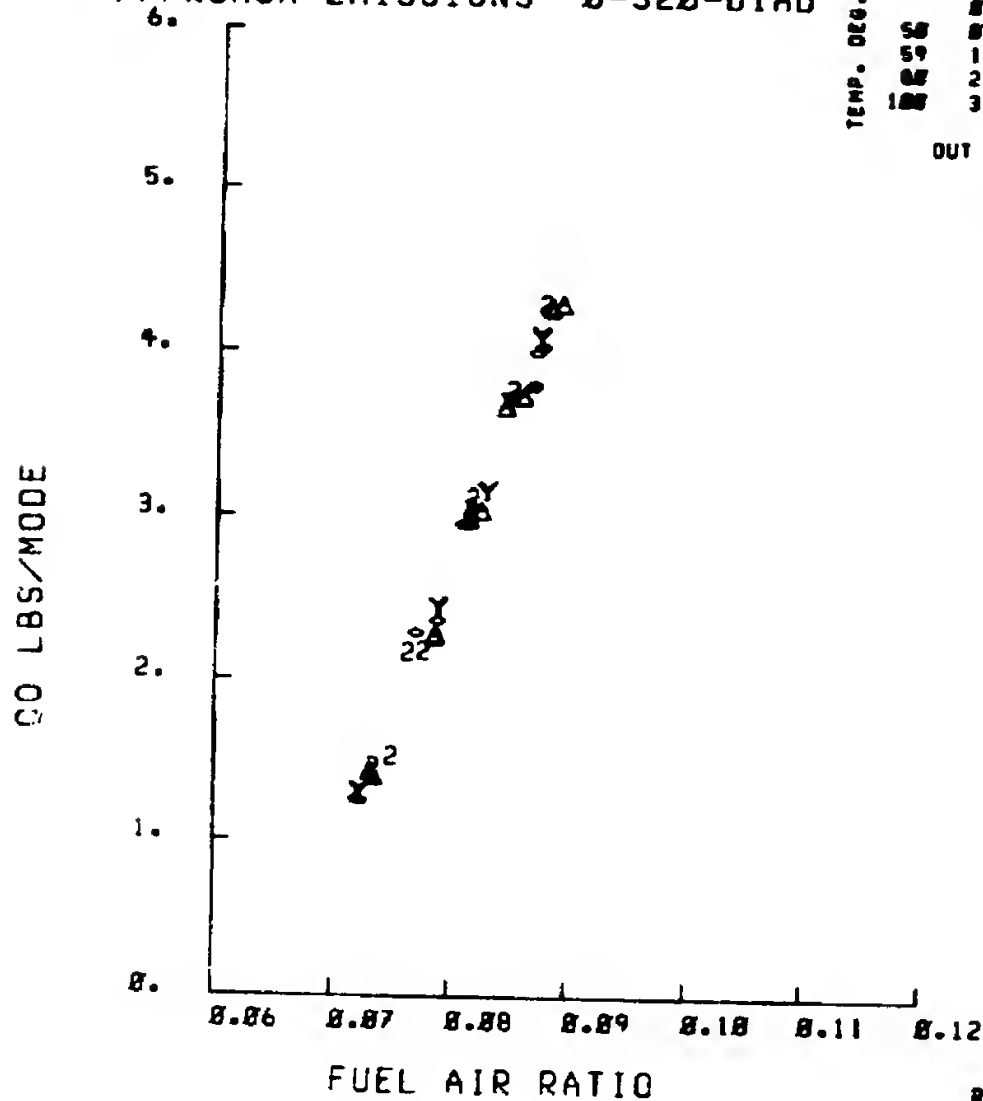
CLIMB	CLIMB
3261	3254
3267	3270
3273 2	3276 2
3279	3282
3285	3288
3377	3380
3383	3386
3389	3392
3395	3398
3401	3404
3499	3501
3504	3507
3510	3513
3516	3519
3525	3526
3468	3471
3474	3477
3480	3483
3486	3489
3492	3495

RDG. 3261

FIGURE 13a

NASA LEAN-OUT DATA

TEMP. 80°F REL. HUM. 0, 30, 60, 80%
APPROACH EMISSIONS Ø-32Ø-DIAD



APPROACH
3262
3268
3277 2
3283
3289
3381
3387
3393 Δ
3399
3405
3502
3508
3514 ○
3520
3527
3472
3478
3484 Y
3490
3496

APPROACH
3265
3274
3280 2
3286
3378
3384
3390
3396 Δ
3402
3499
3505
3511 ○
3517
3523
3469
3475
3481 Y
3487
3493

FIGURE 13e

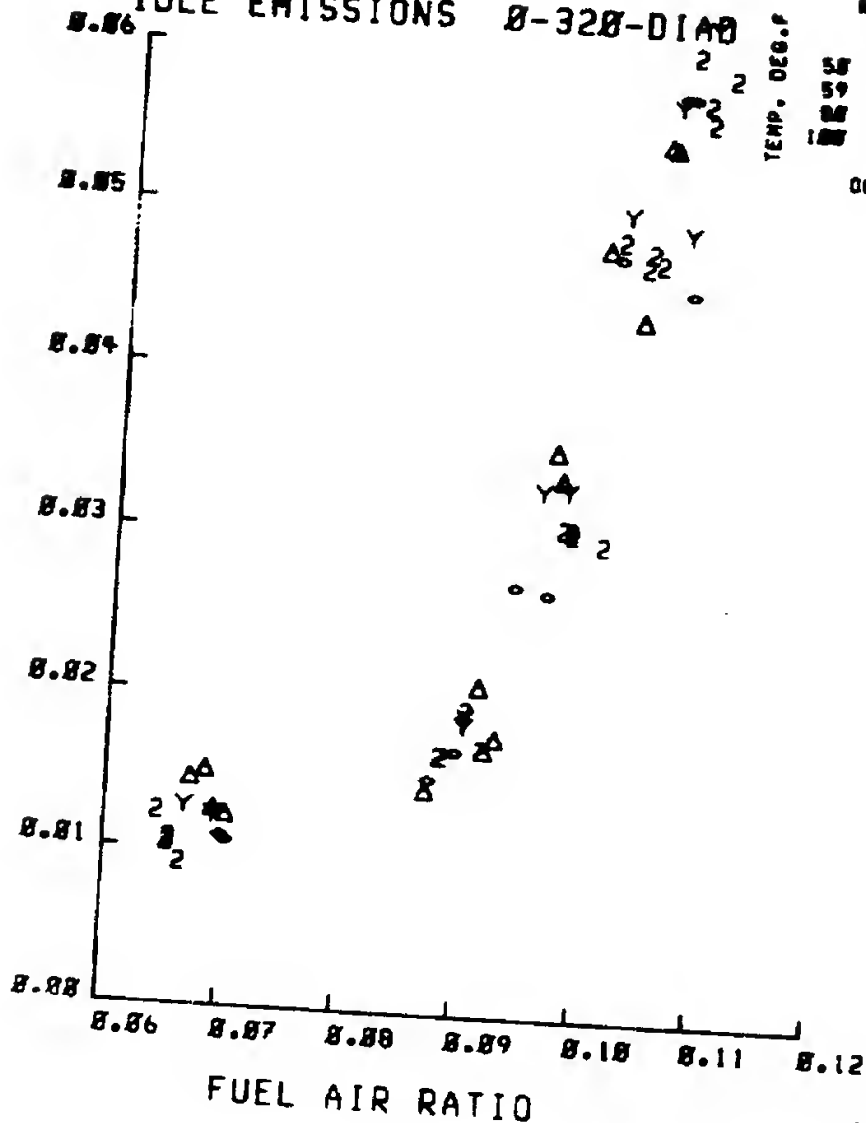
NASA LEAN-OUT DATA

TEMP. 80°F REL HUM. 0, 30, 60, 80%

IDLE EMISSIONS 8-328-DIA

REL. HUMIDITY
8 30 60 80
+ X Y N
OUT OF RANGE -

HC LBS/MODE



ORIGINAL PAGE IS
OF POOR QUALITY

IDLE
3293
3296
3301
3305
3309
3313 2
3320
3322
3328
3337
3345
3348
3350
3356 Δ
3372
3406
3411
3419
3422
3431 ○
3433
3439
3446
3451
3453 Y
3458
3463

IDLE
3295
3300
3304
3308
3310 2
3314
3321
3326
3331
3335
3346
3349
3351
3358 Δ
3374
3410
3414
3420
3425
3432 ○
3437
3442
3447
3452
3457 Y
3462 Y
3466

RD8.3293

FIGURE 13f

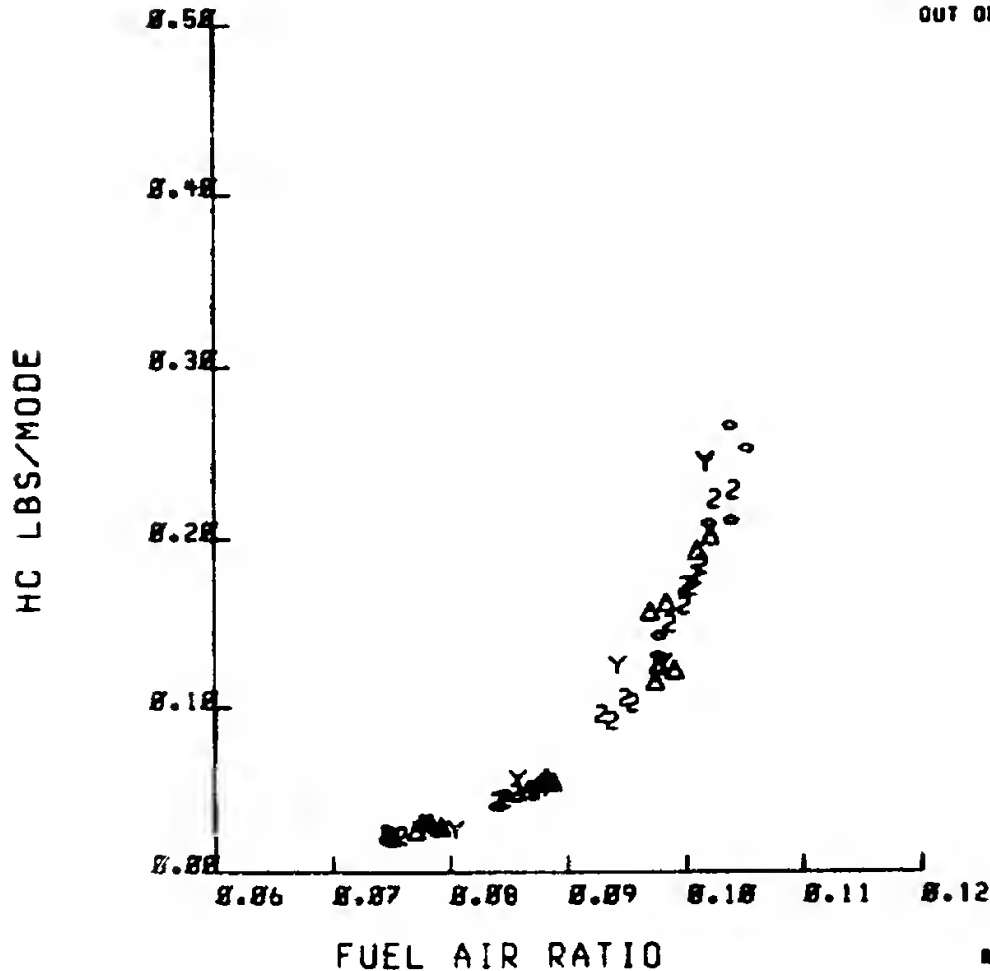
TEMP. 80°F REL HUM. 0, 30, 60, 80%

REL. HUMIDITY

TEMP. DEG. F.

1	2	3	4	5
6	7	8	9	0
A	B	C	D	E
F	G	H	I	J
K	L	M	N	O
P	Q	R	S	T
U	V	W	X	Y
Z				

OUT OF RANGE →



TAXI		TAXI	
3291		3292	
3297		3298	
3302		3303	
3306		3307	
3311		3312	2
3315	2	3316	
3319		3323	
3324		3327	
3329		3330	
3333		3334	
3342		3343	
3344		3347	
3352		3353	
3354	Δ	3355	
3361		3362	Δ
3363		3364	
3407		3408	
3412		3413	
3417		3421	
3423		3424	
3427	○	3429	○
3434		3435	
3440		3441	
3444		3445	
3449		3450	
3455	Y	3456	Y
3459		3460	
3464		3465	

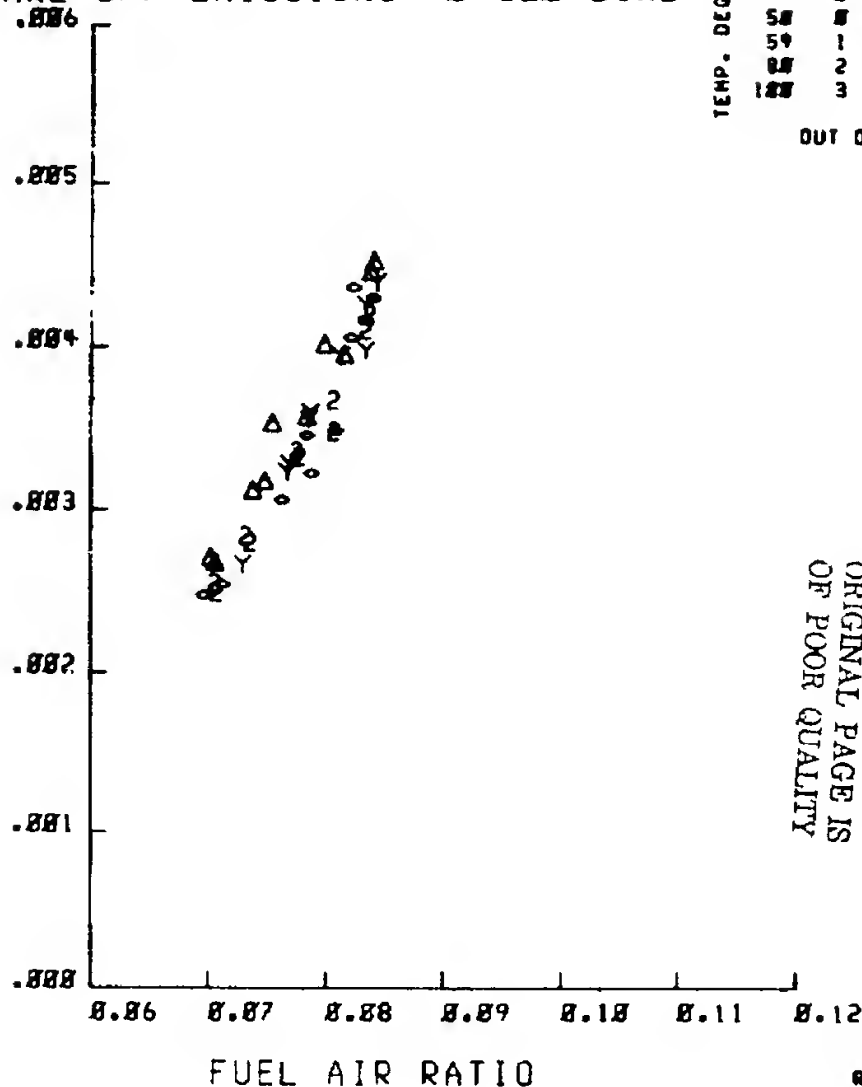
FIGURE 13g

NASA LEAN-OUT DATA

TEMP. 80°F REL HUM. 0, 30, 60, 80%
TAKE OFF EMISSIONS Ø-32Ø-DIAD

TEMP. DEG.F	REL.HUMIDITY			
	Ø	2Ø	4Ø	8Ø
	5Ø	Ø	Ø	+
	59	1	Ø	X
	8Ø	2	Δ	Y
12Ø	3	Ø	Ø	Z
OUT OF RANGE -				

HC LBS/MODE



TAKE-OFF
3260
3266
3272 2
3278
3284
3376
3382
3388 Δ
3394
3400
3497
3503
3509 Ø
3515
3521
3467
3473
3479 Y
3485
3491

TAKE-OFF
3263
3269
3275 2
3281
3287
3379
3385
3391 Δ
3397
3403
3500
3506
3512 Ø
3518
3524
3470
3476 Y
3482
3488

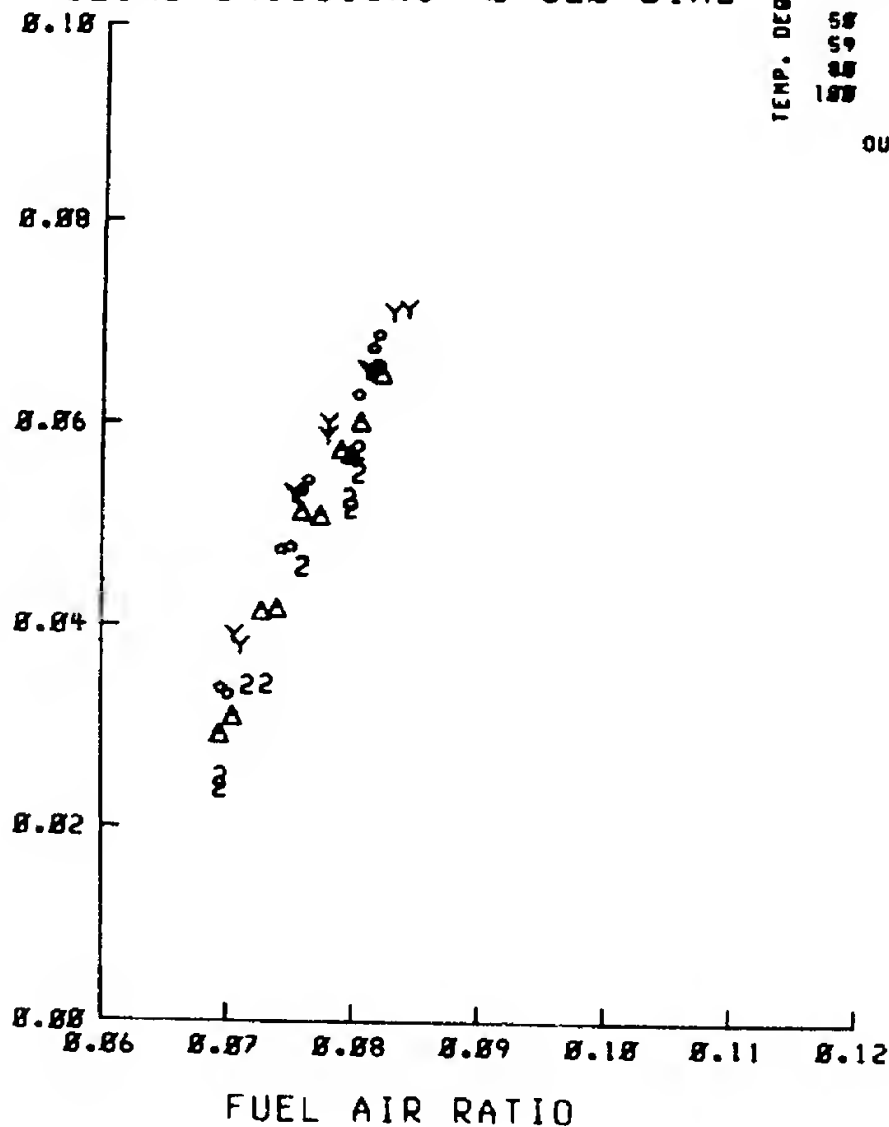
FIGURE 13h

NASA LEAN-OUT DATA

TEMP. 80°F REL HUM. 0, 30, 60, 80%

CLIMB EMISSIONS Ø-32Ø-DIAD

HC LBS/MODE



CLIMB	CLIMB
3261	3264
3267	3270
3273	3276
3279	3282
3285	3288
3377	3380
3383	3386
3389	3392
3395	3398
3401	3404
3498	3501
3504	3507
3510	3513
3516	3519
3525	3526
3468	3471
3474	3477
3480	3483
3486	3489
3492	3495

FIGURE 131

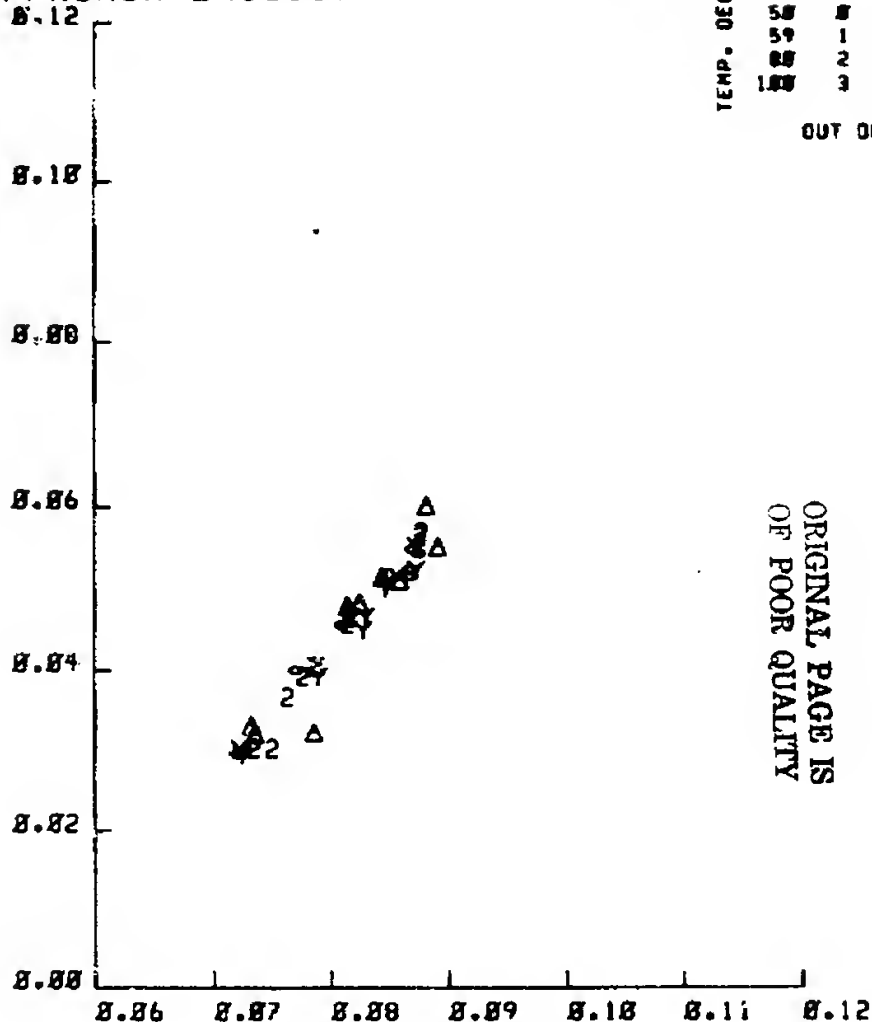
ROG. 3261

NASA LEAN-OUT DATA

TEMP. 80°F REL. HUM. 0, 30, 60, 80%

APPROACH EMISSIONS 8-328-DIAD

HC LBS/MODE



FUEL AIR RATIO

TEMP. DEG. F	REL. HUMIDITY			
	0	30	60	80
50	0	0	0	+
54	1	0	0	X
80	2	Δ	0	Y
100	3	Δ	Δ	Z

OUT OF RANGE -

APPROACH
3262
3268
3277 2
3283
3289
3381
3387
3393 Δ
3399
3405
3502
3508
3514 0
3520
3527
3472
3478
3484
3490 Y
3496

APPROACH
3265
3274
3280 2
3286
3378
3384
3390
3396 Δ
3402
3499
3505
3511 0
3517
3523
3469
3475
3481 Y
3487
3493

RD8.3262

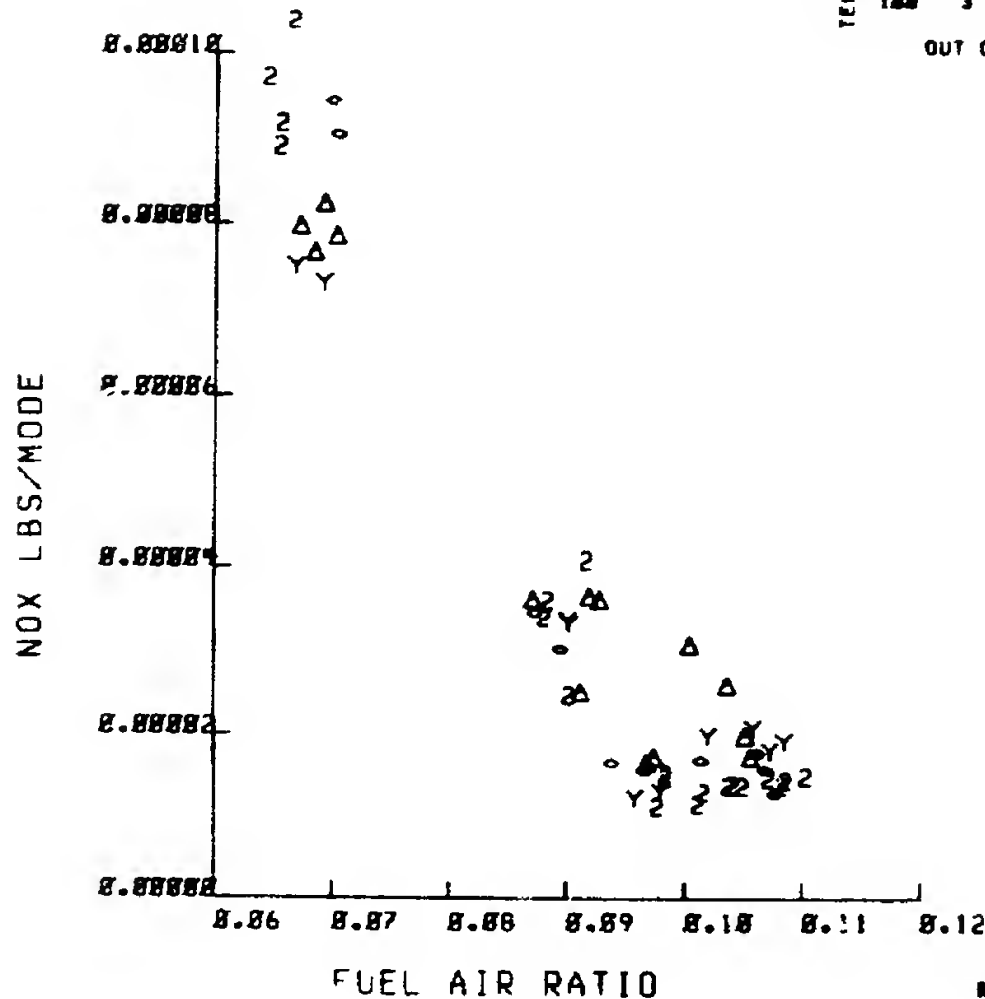
FIGURE 13j

NASA LEAN-OUT DATA

TEMP. 80°F REL HUM. 0, 30, 60, 80%

IDLE EMISSIONS B-32B-DIAD

TEMP. DEG. F	REL. HUMIDITY			
	5	30	60	80
	50	1	0	+
	59	1	0	x
	80	2	Δ	Y
100	3	Δ	Δ	Z
OUT OF RANGE -				



IDLE	IDLE
3293	3295
3296	3300
3301	3304
3305	3308
3309	3310 2
3313 2	3314
3320	3321
3322	3326
3328	3331
3332	3335
3345	3346
3348	3349
3350	3351
3356 Δ	3358 Δ
3372	3374
3406	3410
3411	3414
3419	3420
3422	3425
3431 0	3432 0
3433	3437
3439	3442
3446	3447
3451	3452
3453 Y	3457 Y
3458	3462
3463	3466

FIGURE 13k

RD8-3293

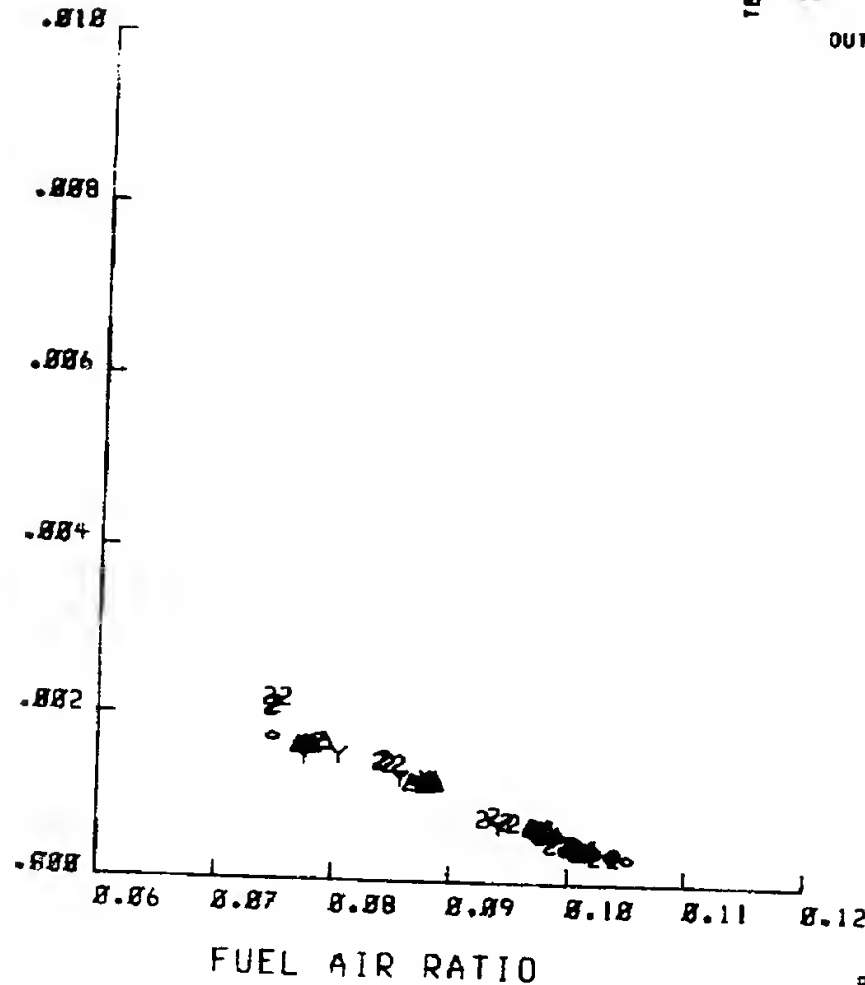
NASA LEAN-OUT DATA

TEMP. 80°F REL HUM. 0, 30, 60, 80%

TAXI EMISSIONS B-328-DIAD

TEMP. DEG.F	REL.HUMIDITY			
	0	30	60	80
	58	0	0	+
	59	1	0	x
	88	2	Δ	Y
	100	3	Δ	Z
	OUT OF RANGE -			

NOX LBS/MODE



TAXI
3291
3297
3302
3306
3311
3315 2
3319
3324
3329
3333
3342
3344
3352
3354 Δ
3361
3363
3407
3412
3417
3423
3427 0
3434
3440
3444
3449
3455 Y
3459
3464

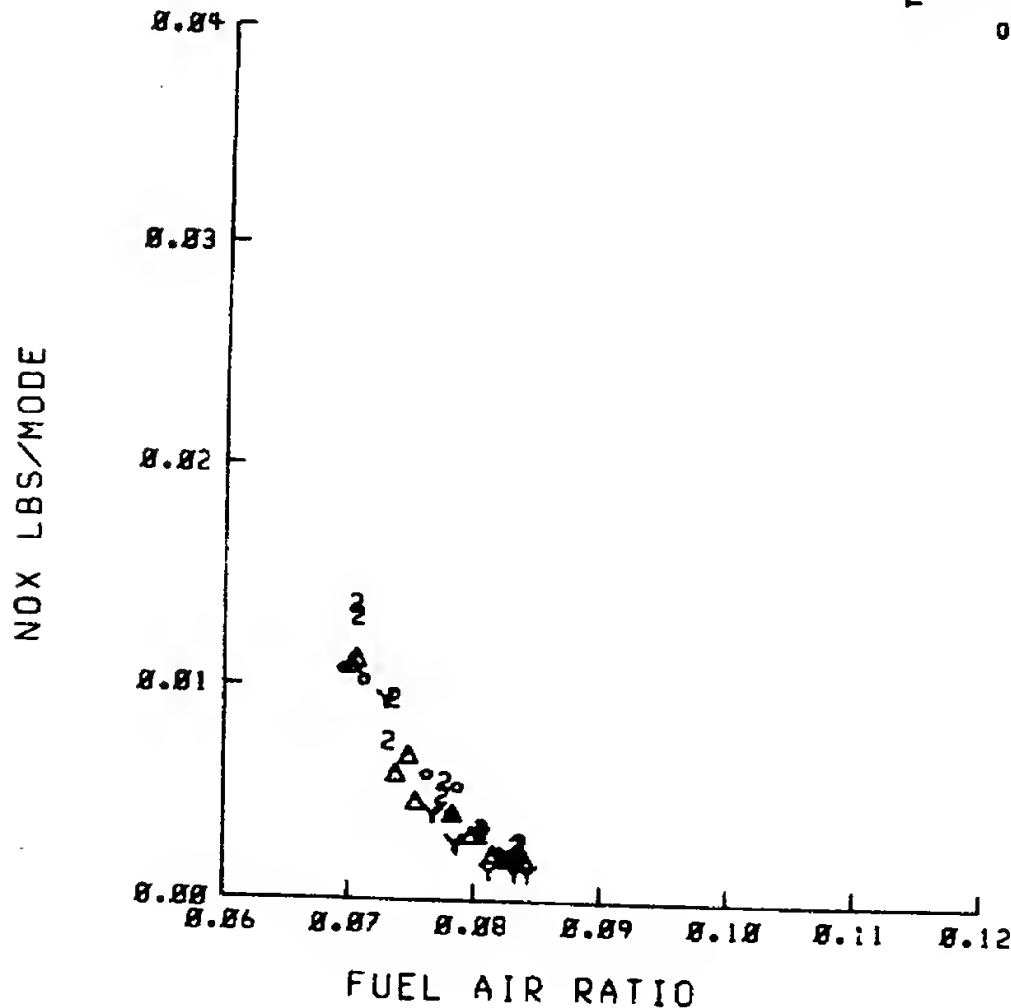
TAXI
3292
3298
3303
3307
3312 2
3316
3323
3327
3330
3334
3343
3347
3353
3355
3362 Δ
3364
3408
3413
3421
3424
3429 0
3435
3441
3445
3450
3456 Y
3460
3465

FIGURE 131

NASA LEAN-OUT DATA

TEMP. 80°F REL HUM. 0, 30, 60, 80%
TAKE OFF EMISSIONS Ø-32Ø-DIAD

TEMP. DEG.F	REL.HUMIDITY			
	Ø	3Ø	6Ø	8Ø
	Ø	Ø	Ø	+
	1	Ø	Ø	X
	2	Δ	•	Y
18Ø	3	✱	✱	Z
OUT OF RANGE -				



TAKE-OFF	TAKE-OFF
3260	3263
3266	3269
3272 2	3275 2
3278	3281
3284	3287
3376	3379
3382	3385
3388 Δ	3391 Δ
3394	3397
3400	3403
3497	3500
3503	3506
3509 Ø	3512 Ø
3515	3518
3521	3524
3467	3470
3473	3476 Y
3479 Y	3482
3485	3488
3491	

RDG.326Ø

FIGURE 13m

NASA LEAN-OUT DATA

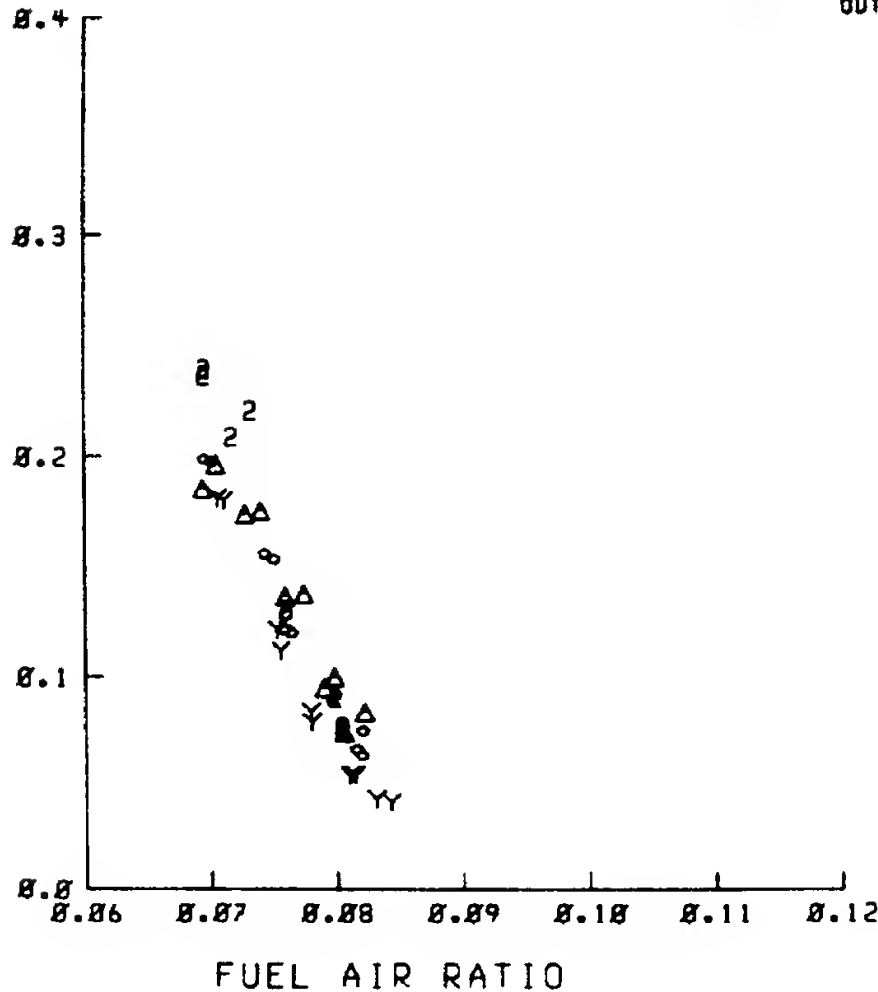
TEMP. 80°F REL HUM. 0, 30, 60, 80%

CLIMB EMISSIONS 8-328-DIAD

TEMP. DEG.F	REL.HUMIDITY			
	8	38	68	88
	58	8	0	+
	59	1	0	X
	88	2	Δ	Y
188	3	★	★	Z

OUT OF RANGE -

NOX LBS/MODE



ORIGINAL PAGE IS
OF POOR QUALITY

CLIMB
3261
3267
3273 2
3279
3285
3377
3383
3389 Δ
3395
3401
3498
3504
3510 0
3516
3525
3468
3474
3480 Y
3486
3492

CLIMB
3264
3270
3276 2
3282
3288
3380
3386
3392 Δ
3398
3404
3501
3507
3513 0
3519
3526
3471
3477
3483 Y
3487
3495

FIGURE 13n

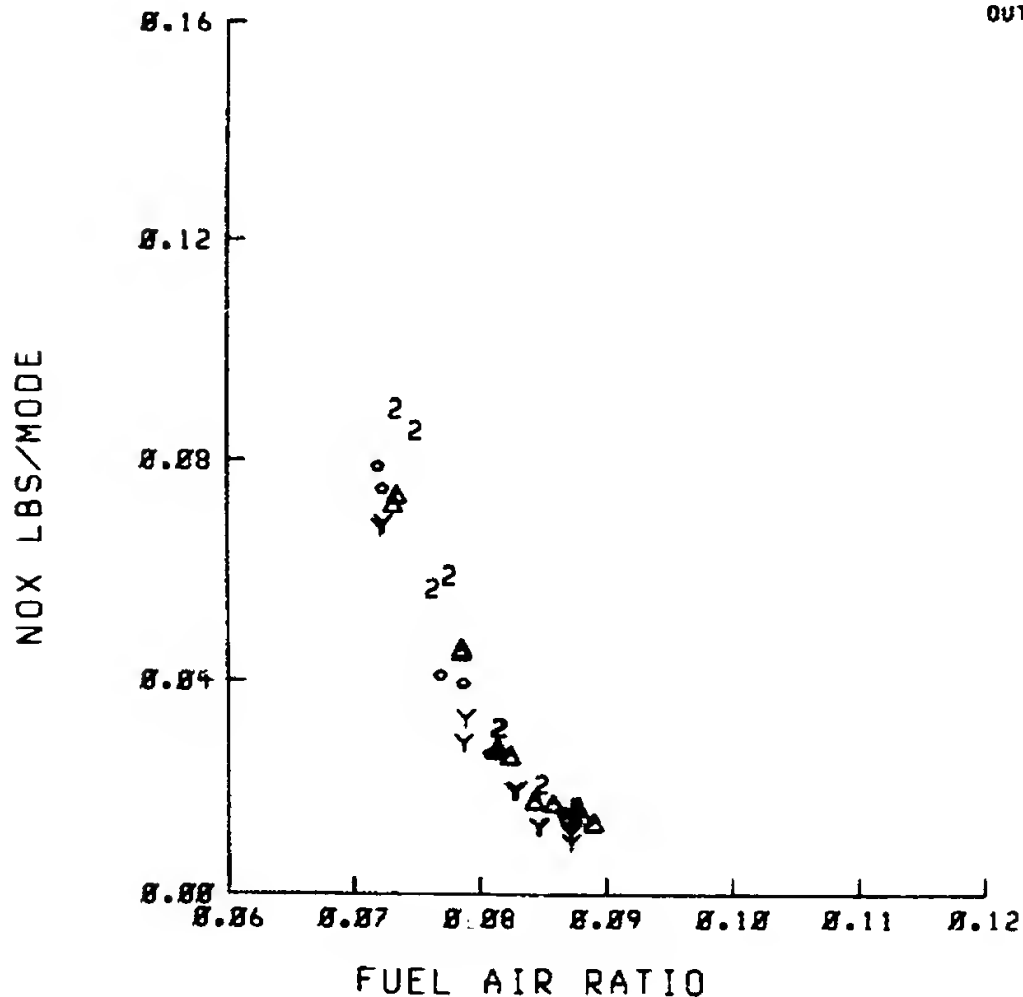
ROG.3261

NASA LEAN-OUT DATA

TEMP. 80°F REL HUM. 0, 30, 60, 80%

APPROACH EMISSIONS Ø-32Ø-DIAD

TEMP. DEG.F	REL.HUMIDITY			
	Ø	3Ø	6Ø	8Ø
	5Ø	Ø	◊	◻
	59	1	○	•
	88	2	△	•
100	3	■	★	2
OUT OF RANGE -				



APPROACH	APPROACH
3262	3265
3268	3274
3277 2	3280 2
3283	3286
3289	3378
3381	3384
3387	3390
3393 Δ	3396 Δ
3399	3402
3405	3499
3502	3505
3508	3511 ◊
3514 ◊	3517
3520	3523
3527	3469
3472	3475
3478	3481 Y
3485 Y	3487
3490	3491
3496	

RDG.3262

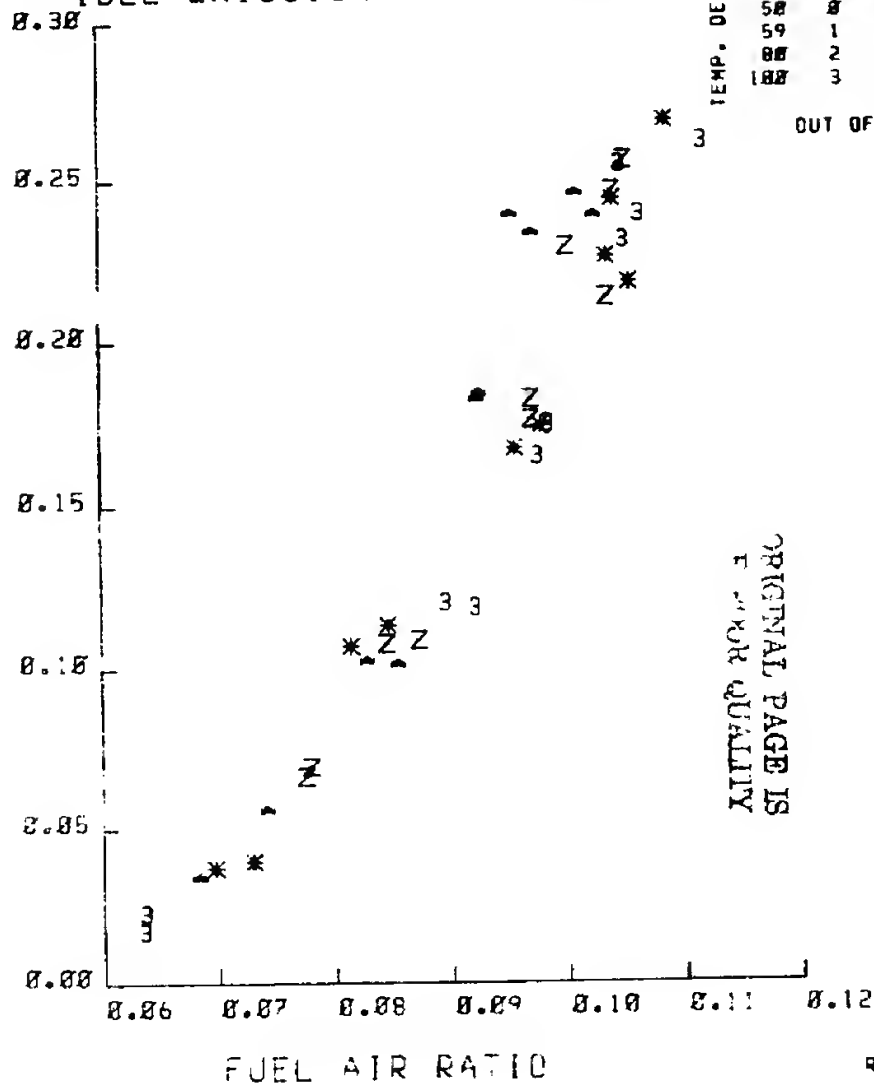
FIGURE 13°

NASA LEAN-OUT DATA

TEMP. 100°F REL. HUM. 0, 30, 60, 80%

IDLE EMISSIONS Ø-32Ø-DIAD

CO LBS/HP HR



IDLE
2983
2990
2995 3
2999
3005
3154
3158
3162 *
3166 *
3170
3176
3184
3192 *
3198
3202
3053
3057
3061 Z
3066
3071

IDLE
2988
2993
2998 3
3002
3008
3157
3161
3165 *
3169
3173
3183
3190
3195 *
3201
3205
3056
3060
3064 Z
3069
3075

RDC-2983

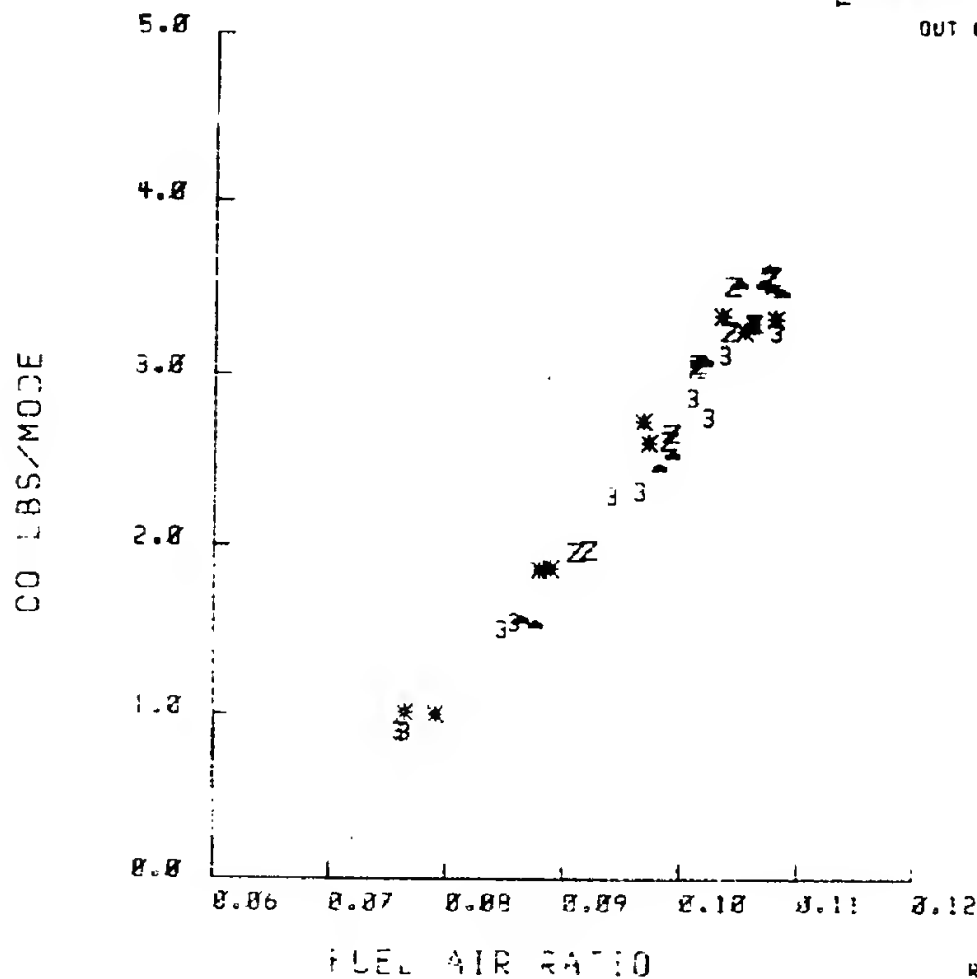
FIGURE 14a

NASA LEAN-OUT DATA

TEMP. 100°F REL. HUM. 0, 30, 60, 80%

TAXI EMISSIONS B-320-DIAD

TEMP. DEG.F	REL. HUMIDITY			
	0	30	60	80
50	0	0	0	+
59	1	0	0	X
80	2	Δ	0	Y
100	3	*	Δ	Z
OUT OF RANGE -				



TAXI	TAXI
2984	2985
2991	2992
2996 3	2997 3
3001	3004
3006	3007
3155	3156
3159	3160
3163 *	3164 *
3167	3168
3171	3172
3177	3180
3185	3187
3188	3193
3194	3199
3200	3203
3204	3054
3055	3058
3059	3062 Z
3063 Z	3067
3068	3072
3073	

FIGURE 14b

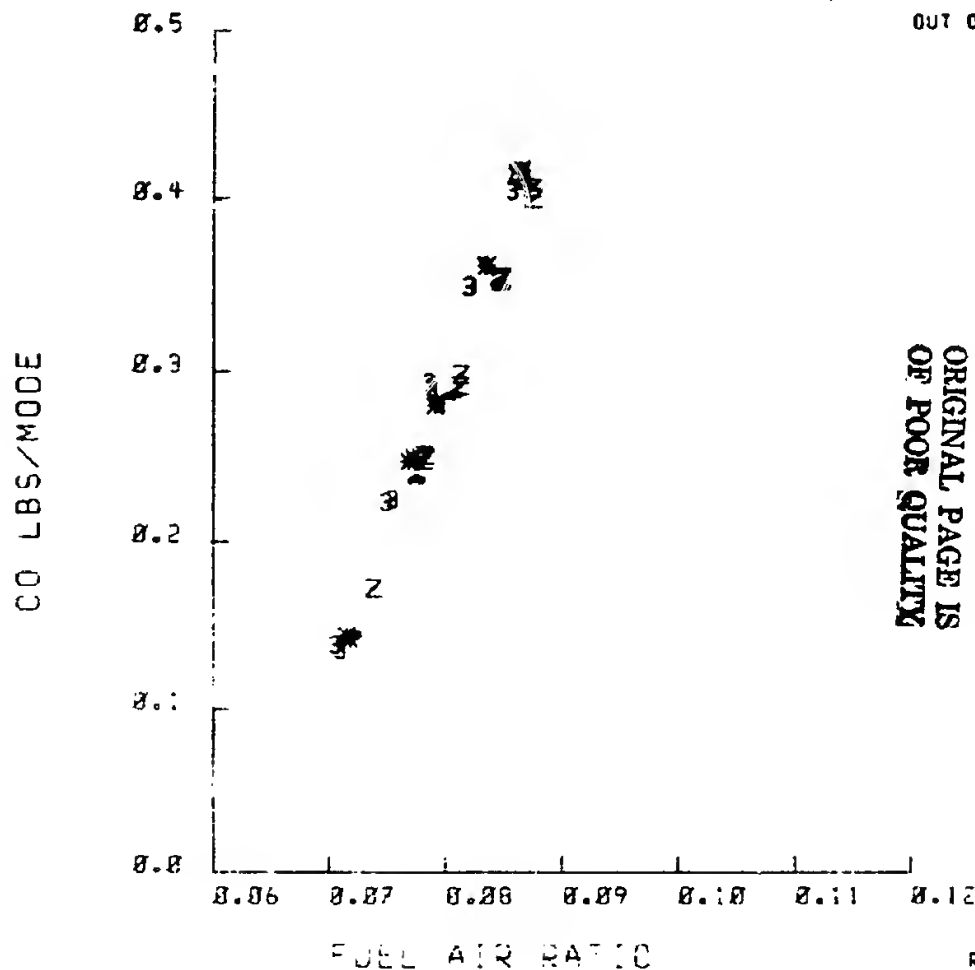
NASA LEAN-OUT DATA

TEMP. 100°F REL. HUM. 0, 30, 60, 80%

TAKE OFF EMISSIONS 8-328-DIAD

TEMP. DEG. F	REL. HUMIDITY			
	0	30	60	80
	50	0	0	+
	77	1	0	X
	88	2	△	Y
	100	3	*	Z

OUT OF RANGE -



TAKE-OFF
3010
3017
3024 3
3032
3038
3121
3126
3132 *
3138
3144
3150
3212
3220
3229 ▲
3239
3247
3079
3085
3099 Z
3105

TAKE-OFF
3014
3020
3027 3
3035
3041
3123
3129
3135 *
3141
3147
3209
3217
3224 ▲
3233
3240
3076
3082
3090 Z
3102
3110

RDG. 3018

FIGURE 14c

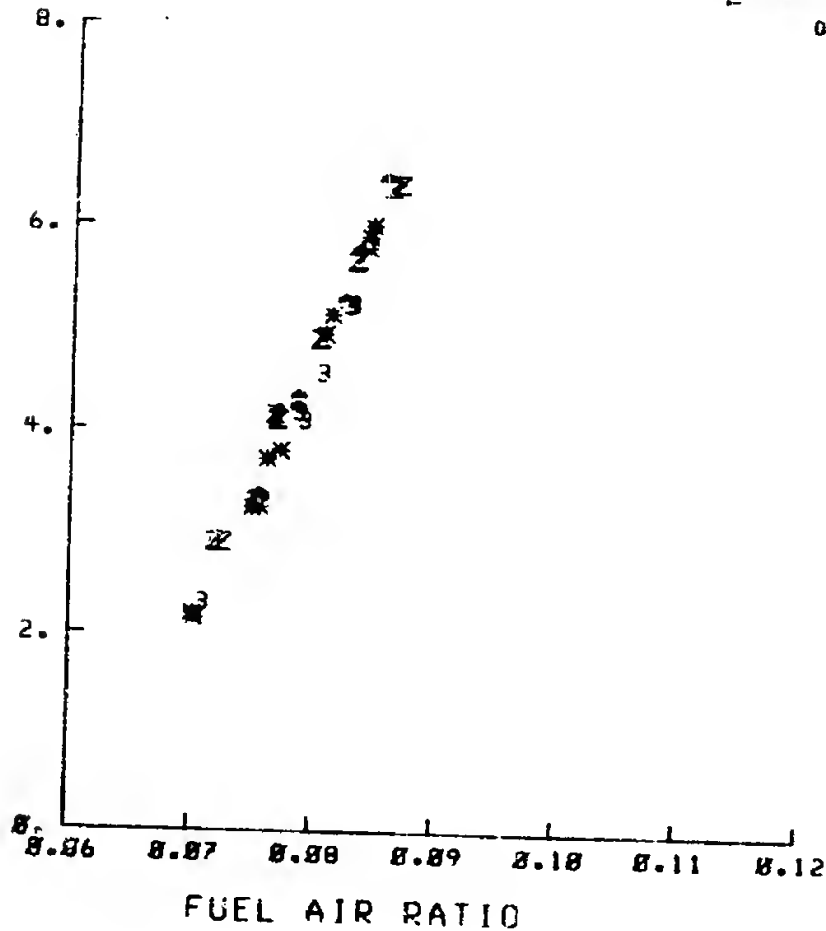
NASA LEAN-OUT DATA

TEMP. 100°F REL. HUM. 0, 30, 60, 80%

CLIMB EMISSIONS Ø-32Ø-DIAD

TEMP. DEG.F	REL. HUMIDITY			
	Ø	3Ø	6Ø	8Ø
	5Ø	Ø	Ø	+
	59	1	Ø	X
	ØØ	2	Δ	Y
	1ØØ	3	■	Z
OUT OF RANGE -				

CO LBS/MODE



CLIMB
3529
3532
3534 3
3537
3122
3127
3133
3139
3145 *
3153
3216
3223
3232 ^
3237
3080
3088
3100 Z
3108
3111

CLIMB
3531
3533
3536 3
3538
3124
3130
3136 *
3142
3151
3215
3218
3227 ^
3236
3077
3087
3097
3106 Z
3109
3112

ROC.3529

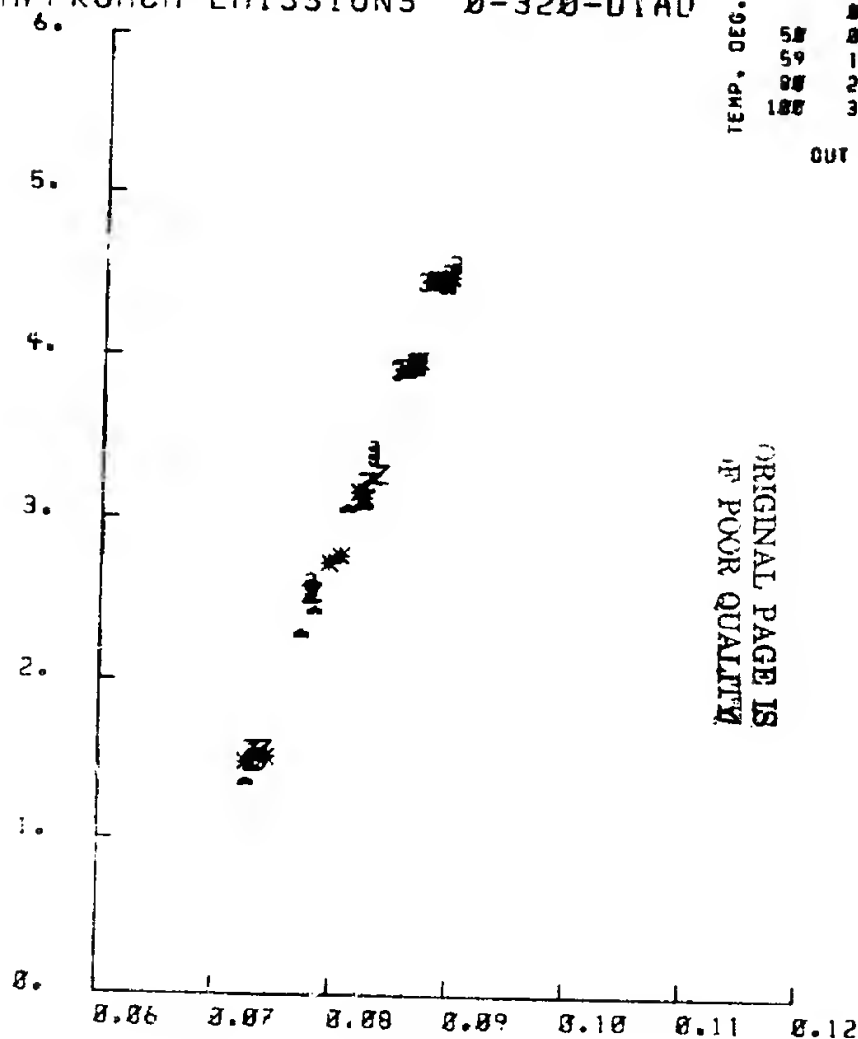
FIGURE 14a

NASA LEAN-OUT DATA

TEMP. 100°F REL. HUM. 0, 30, 60, 80%

APPROACH EMISSIONS Ø-32Ø-DIAD

CO LBS/Ø7 ØØ



FUEL AIR RATIO

ØØØ.3Ø13

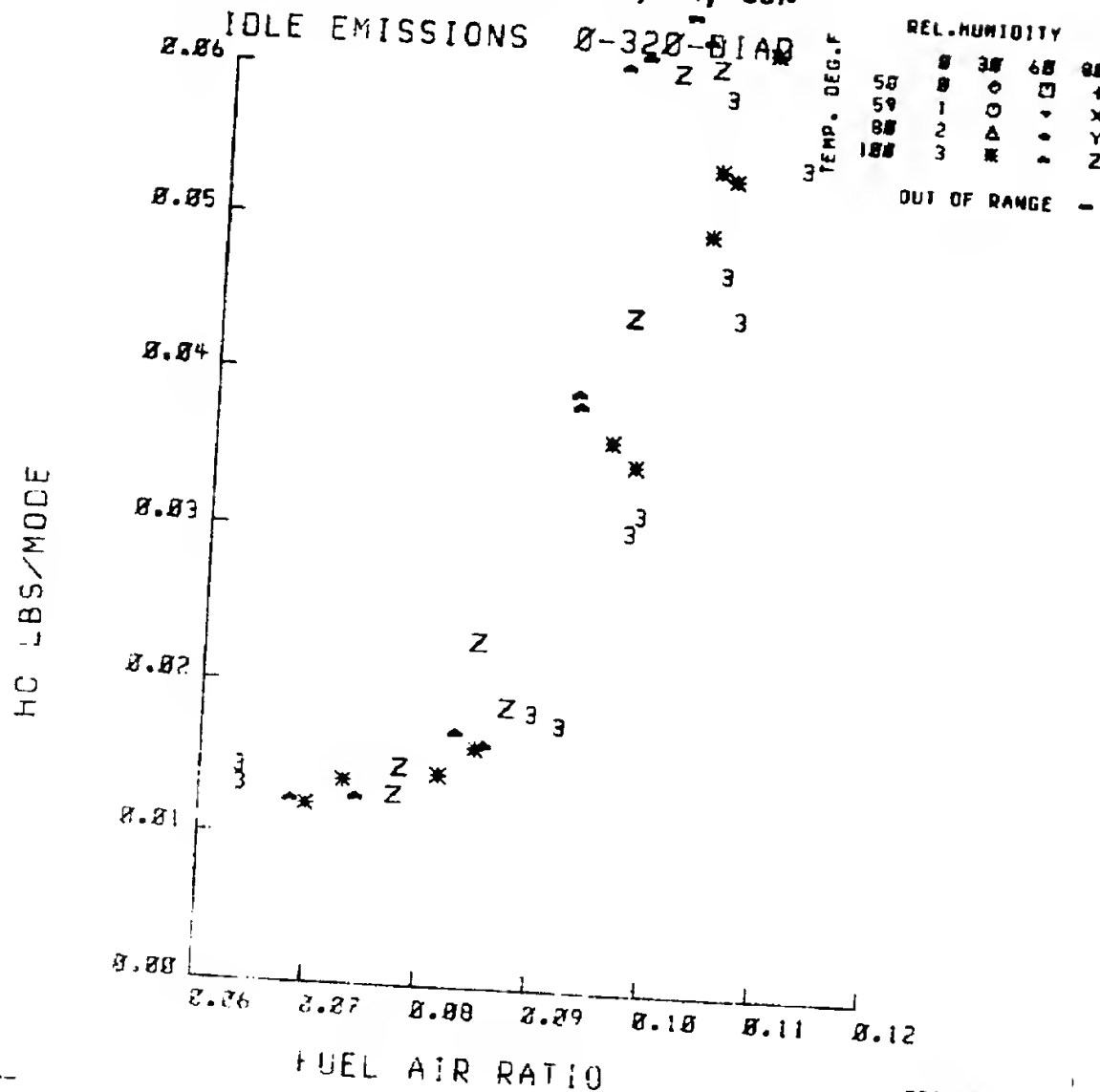
APPROACH	
3013	
3019	
3026	3
3034	
3040	
3125	
3131	
3137	*
3143	
3149	
3211	
3219	
3226	✱
3235	
3244	
3Ø78	
3Ø84	
3Ø98	Z
31Ø4	
3113	

APPROACH	
3016	
3023	
3031	3
3057	
3043	
3128	
3134	
3140	*
3146	
3152	
3214	
3222	
3231	✱
3238	
3251	
3Ø81	
3Ø89	
31Ø1	Z
31Ø7	
3116	

FIGURE 14e

NASA LEAN-OUT DATA

TEMP. 100°F REL. HUM. 0, 30, 60, 80%



IDLE	
2983	
2990	
2995	3
2999	
3005	
3154	
3158	
3162	*
3166	*
3170	
3176	
3184	
3192	▲
3198	
3202	
3053	
3057	
3061	Z
3066	
3071	

IDLE	
2988	
2993	
2998	3
3002	
3008	
3157	
3161	
3165	*
3169	*
3173	
3183	
3190	
3195	▲
3201	
3205	
3056	
3060	
3064	Z
3069	
3075	

FIGURE 14f

RDG. 2983

NASA LEAN-OUT DATA

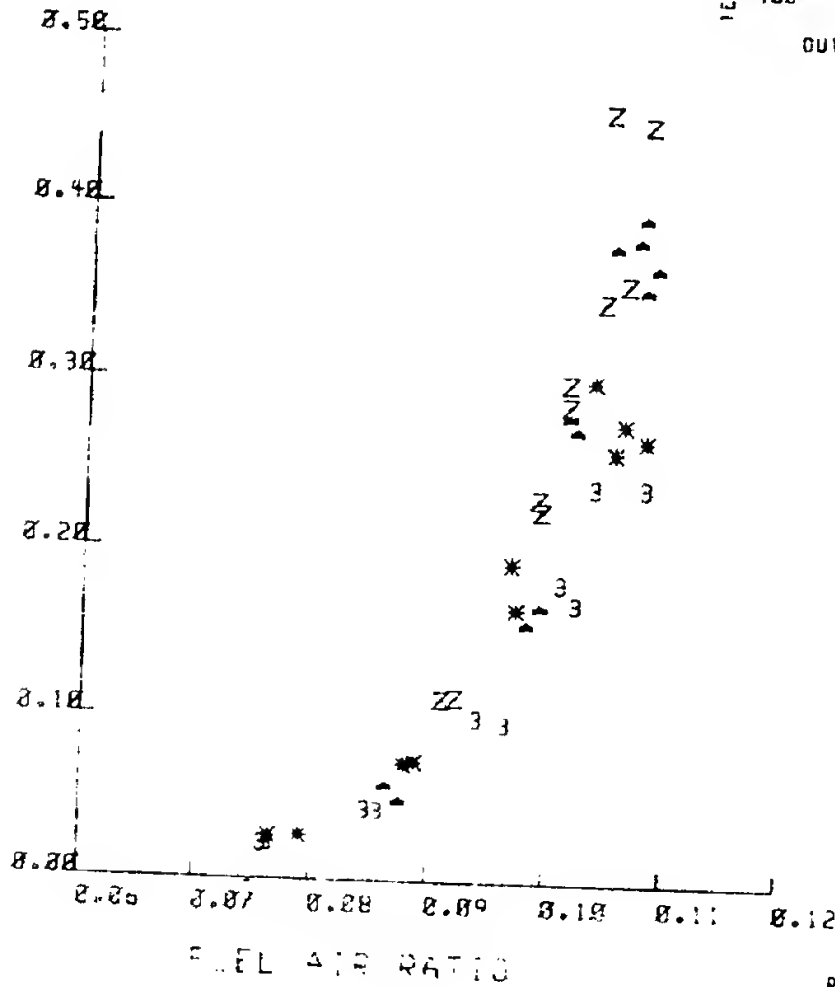
TEMP. 100°F REL. HUM. 0, 30, 60, 80%

TAXI EMISSIONS 0-320-DIAD

TEMP. DEG.F	REL.HUMIDITY			
	0	30	60	80
50	0	0	0	0
59	1	0	0	X
80	2	0	0	Y
100	3	0	0	Z

OUT OF RANGE -

10 LBS/NOZ



ORIGINAL PAGE IS
OF POOR QUALITY

TAXI
2984
2991
2996 3
3001
3006
3155
3159
3163 *
3167
3171
3177
3185
3188
3194
3200
3204
3055
3059
3063 Z
3068
3073

TAXI
2985
2992
2997 3
3004
3007
3156
3160
3164 *
3168
3172
3180
3187
3193
3199
3203
3054
3058
3062 Z
3067
3072

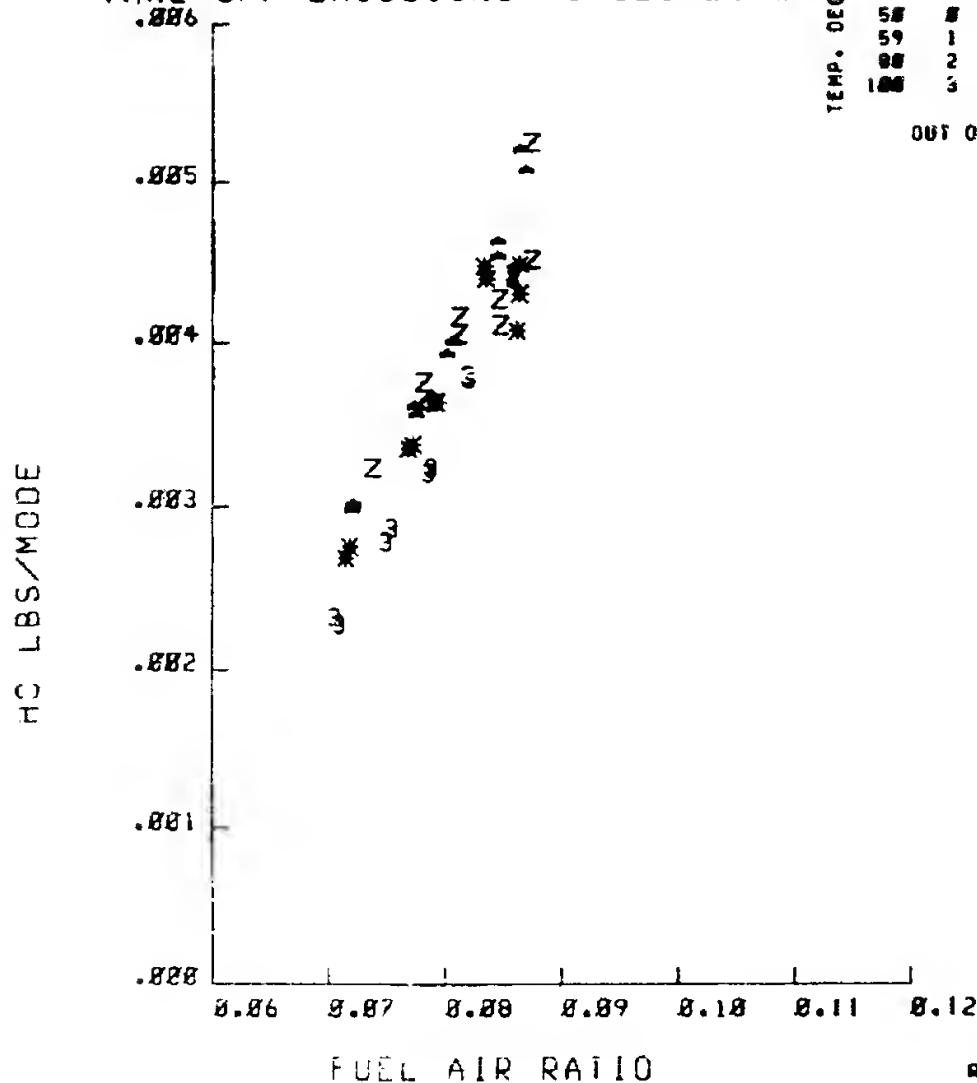
FIGURE 14g

ADG-2904

NASA LEAN-OUT DATA

TEMP. 100°F REL. HUM. 0, 30, 60, 80%

TAKE OFF EMISSIONS Ø-32Ø-DIAD



TAKE-OFF	
3010	
3017	
3024	3
3032	
3038	
3121	
3126	
3132	*
3138	
3144	
3150	
3212	
3220	
3229	
3239	
3247	
3079	
3085	
3099	Z
3105	

TAKE-OFF	
3014	
3020	
3027	3
3035	
3041	
3123	
3129	
3135	*
3141	
3147	
3209	
3217	
3224	
3233	
3240	
3076	
3082	
3090	Z
3102	
3110	

FIGURE 14h

NASA LEAN-OUT DATA

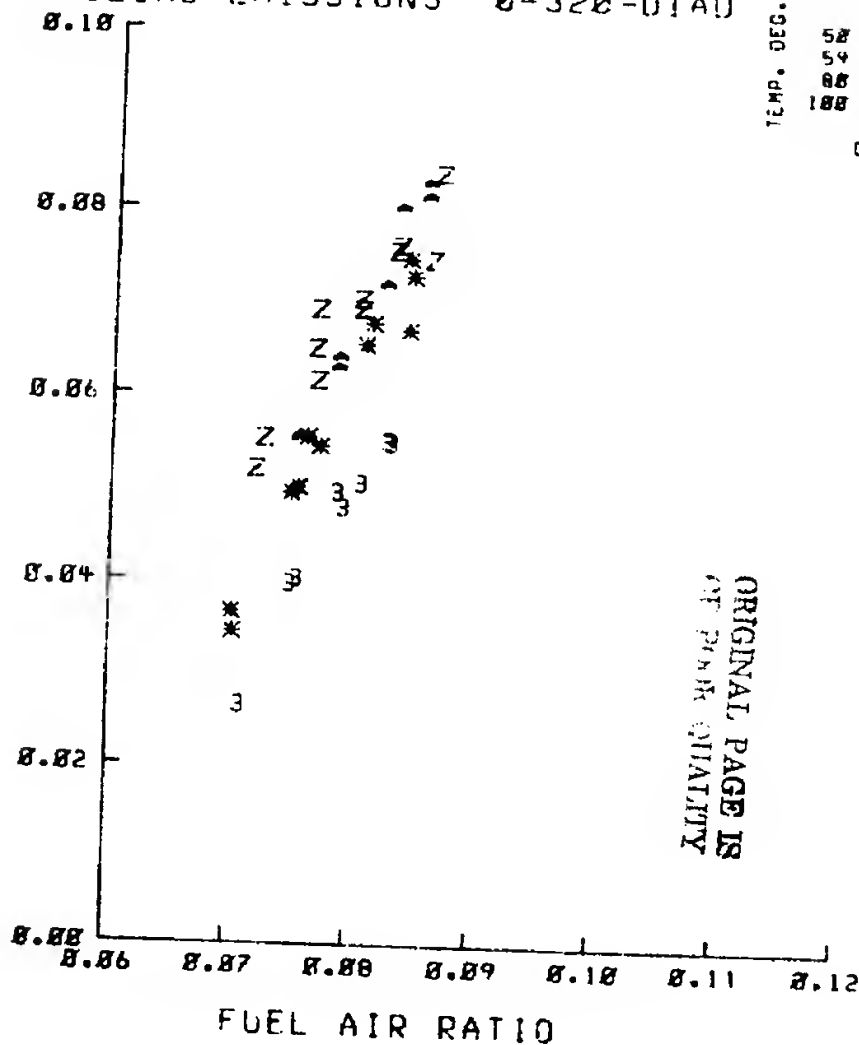
TEMP. 100°F REL. HUM. 0, 30, 60, 80%

CLIMB EMISSIONS 8-328-01AD

TEMP. DEG. F	REL. HUMIDITY	REL. HUMIDITY	REL. HUMIDITY	REL. HUMIDITY
52	0	30	60	80
54	0	30	60	80
56	1	30	60	80
58	2	30	60	80
60	3	30	60	80

OUT OF RANGE -

HC LBS/MODE



CLIMB	CLIMB
3529	3531
3532	3533
3534 3	3536 3
3537	3538
3122	3124
3127	3130
3133	3136 *
3139	3142 *
3145 *	3151
3153	3215
3216	3218
3223	3227 *
3237	3236
3237	3077
3080	3087
3088	3097
3100 Z	3106 Z
3108	3109
3111	3112

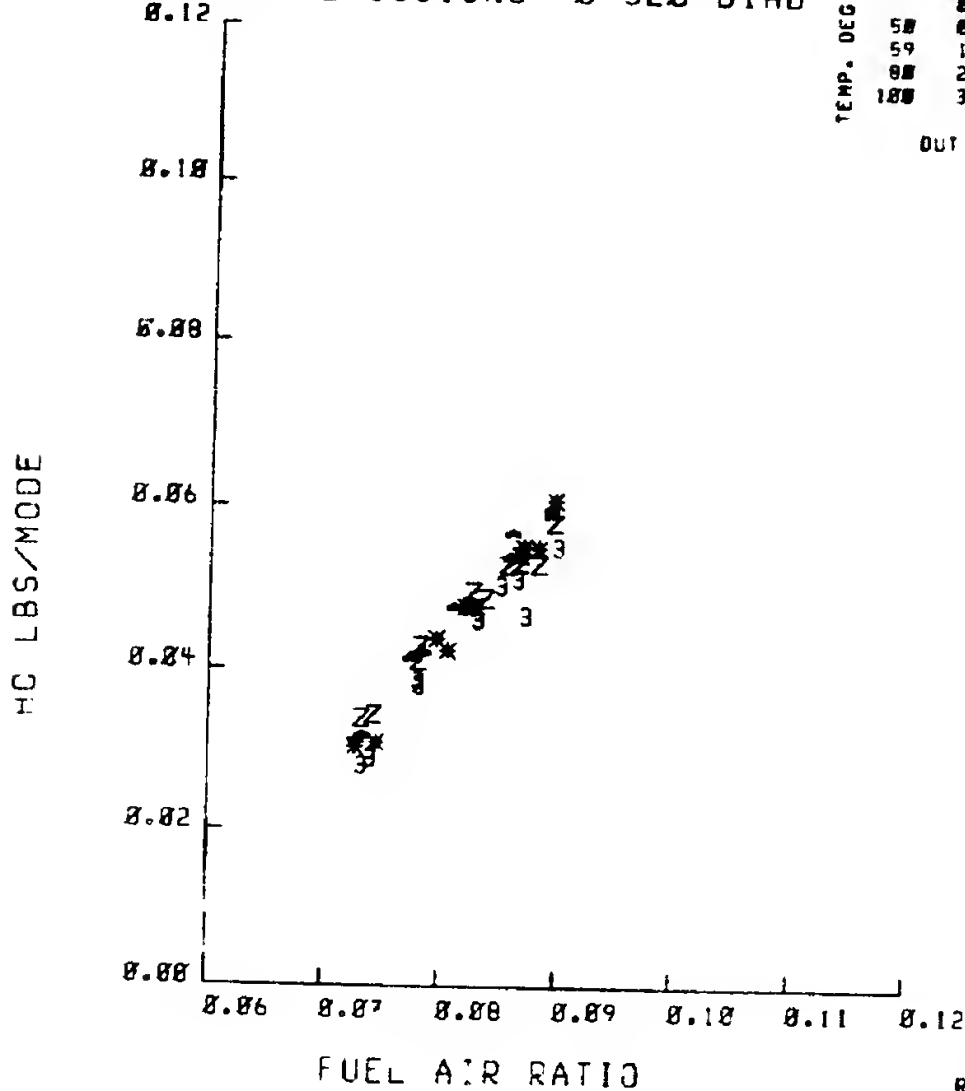
ROC. 3529

FIGURE 14i

NASA LEAN-OUT DATA

TEMP. 100°F REL. HUM. 0, 30, 60, 80%

APPROACH EMISSIONS Ø-32Ø-DIAD



TEMP. DEG.F	REL. HUMIDITY			
	0	30	60	80
	58	8	0	+
	59	1	0	X
	88	2	Δ	Y
188	3	M	Δ	Z
OUT OF RANGE -				

APPROACH
3013
3019
3026 3
3034
3040
3125
3131
3137 *
3143
3149
3211
3219
3226 *
3235
3244
3078
3084
3098 Z
3104
3113
0

APPROACH
3016
3023
3031 3
30
30
3128
3134
3140 *
3146
3152
3214
3222
3231 *
3238
3251
3081
3089
3101 Z
3107
3116

ROG. 3813

FIGURE 14j

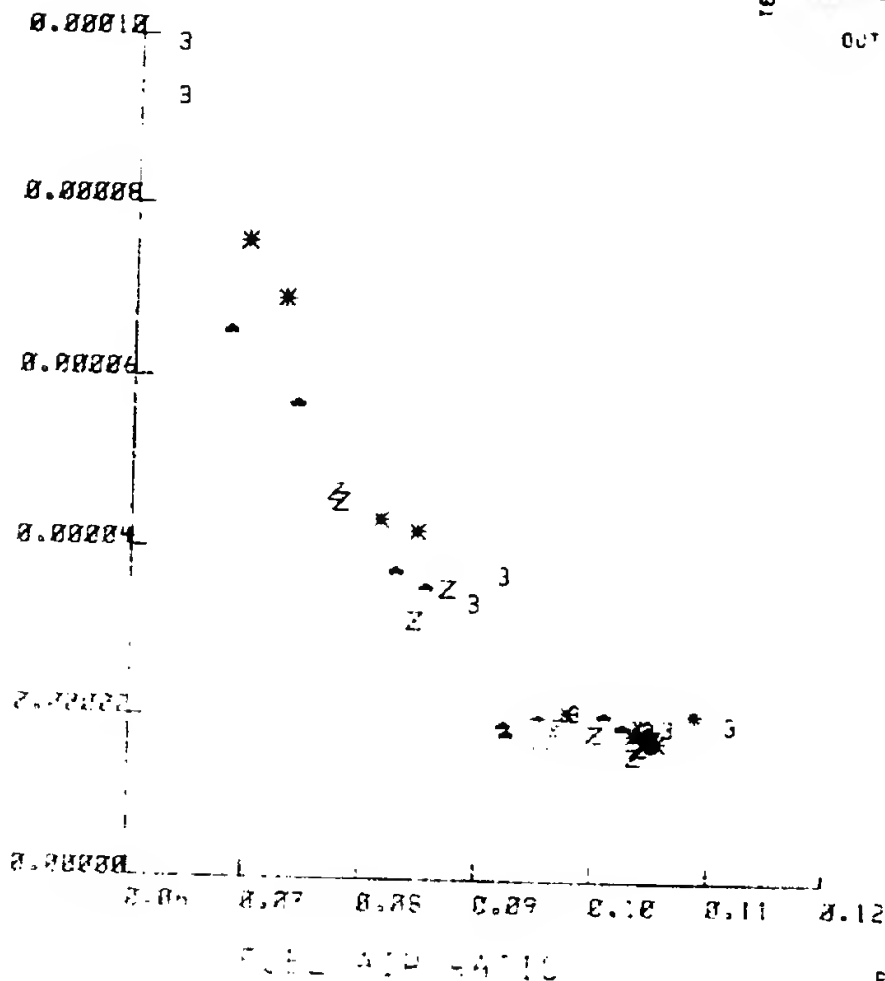
NASA LEAN-OUT DATA

TEMP. 100°F REL HUM. 0, 30, 60, 80%

IDLE EMISSIONS Ø-32Ø-DIAD

TEMP. DEG. F	REL. HUMIDITY			
	Ø	3Ø	6Ø	8Ø
	52	Ø	Ø	+
	59	1	Ø	x
	88	2	Δ	Y
188	3	*	•	Z

OUT OF RANGE -



IDLE	IDLE
2983	2988
2990	2993
2995 3	2998 3
2999	3002
3005	3008
3154	3157
3158	3161
3162	3165 *
3166 *	3169 *
3170	3173
3176	3183
3184	3190
3192 *	3195 *
3198	3201
3202	3205
3053	3056
3057	3060
3061 Z	3064 Z
3066	3069
3071	3075

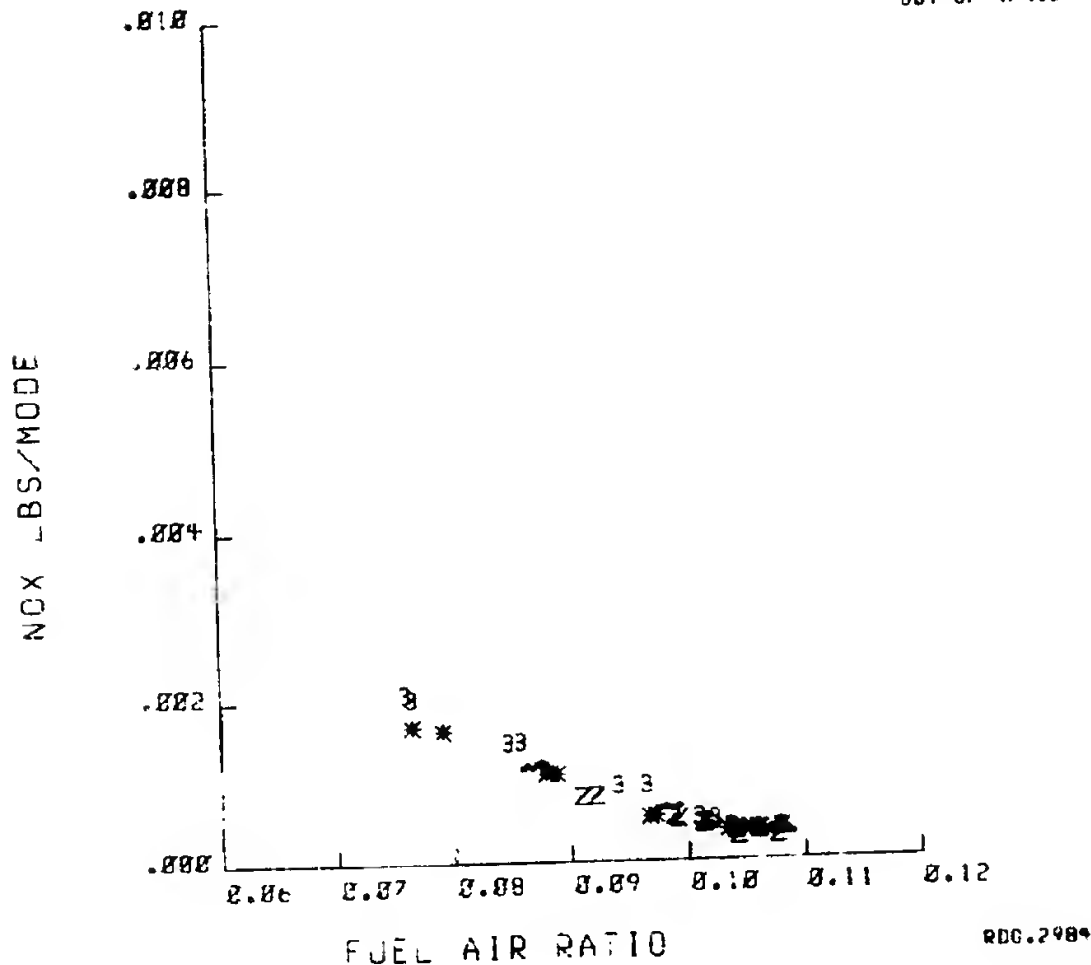
FIGURE 14k

NASA LEAN-OUT DATA

TEMP. 100°F REL. HUM. 0, 30, 60, 80%

TAXI EMISSIONS Ø-32Ø-DIAD

TEMP. DEG.F	REL. HUMIDITY			
	Ø	3Ø	6Ø	8Ø
	58	Ø	Ø	+
	59	1	Ø	X
	ØØ	2	Δ	Y
1ØØ	3	■	▲	Z
OUT OF RANGE -				



TAXI
2984
2991
2996 3
3001
3006
3155
3159
3163 *
3167
3171
3177
3185
3188 *
3194
3200
3204
3055
3059
3063 Z
3068
3073

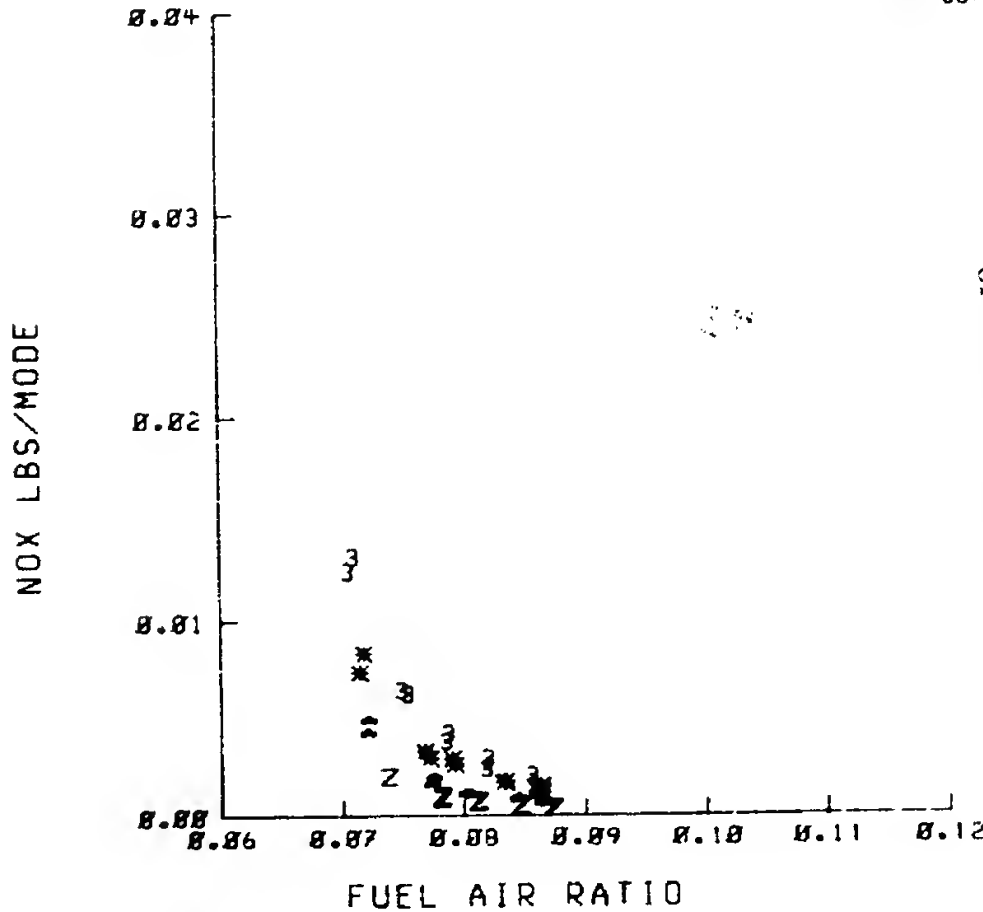
TAXI
2985
2992
2997 3
3004
3007
3156
3160
3164 *
3168
3172
3180
3187
3193 *
3199
3203
3054
3058
3062 Z
3067
3072

FIGURE 141

NASA LEAN-OUT DATA

TEMP. 100°F REL HUM. 0, 30, 60, 80%
TAKE OFF EMISSIONS Ø-32Ø-D1AD

TEMP. DEG. F	REL. HUMIDITY			
	Ø	3Ø	6Ø	9Ø
	5Ø	Ø	Ø	+
	59	1	Ø	X
	88	2	Δ	Y
	1ØØ	3	Δ	Z
OUT OF RANGE -				



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TAKE-OFF	TAKE-OFF
3013	3014
3017	3020
3024 3	3027 3
3032	3035
3038	3041
3121	3123
3126	3129
3132 *	3135 *
3138	3141
3144	3147
3150	3209
3212	3217
3220	3224 *
3229 *	3233
3239	3240
3247	3076
3077	3082
3085	3090 Z
3099 Z	3102
3105	3110

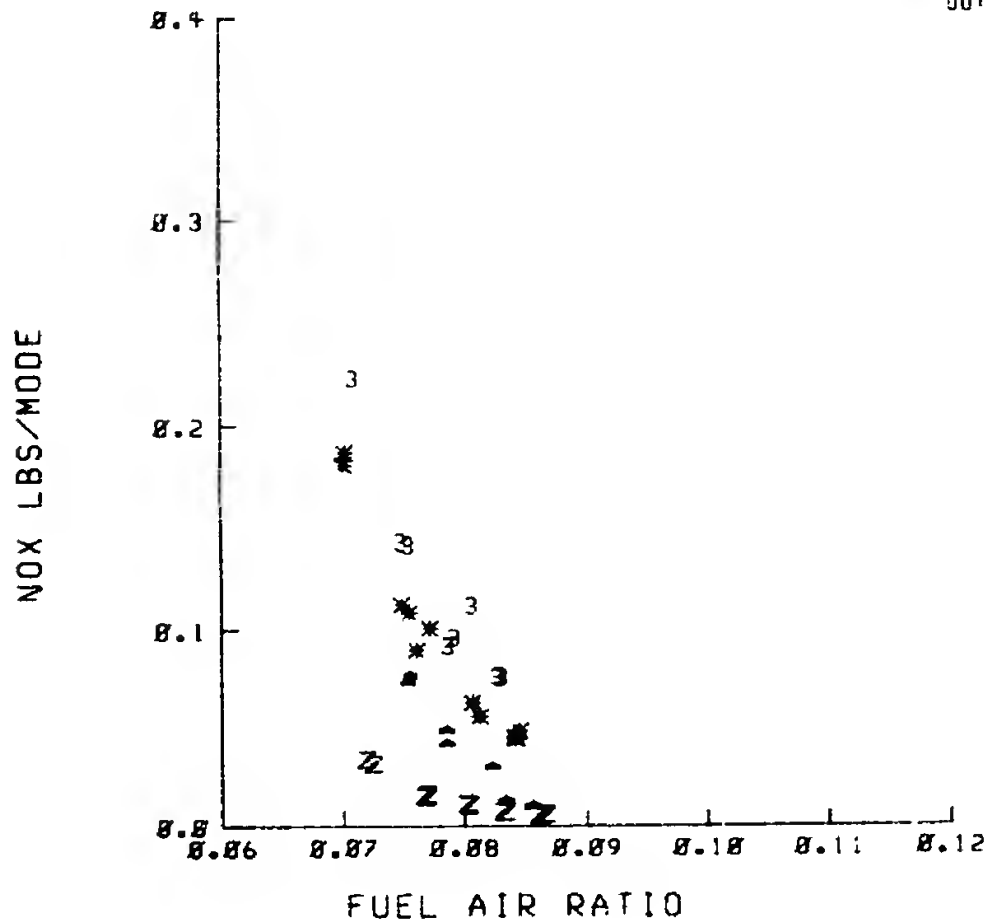
FIGURE 14m

NASA LEAN-OUT DATA

TEMP. 100°F REL. HUM. 0, 30, 60, 80%

CLIMB EMISSIONS Ø-32Ø-DIAD

TEMP. DEG.°	REL. HUMIDITY			
	Ø	3Ø	6Ø	8Ø
	5Ø	Ø	◊	◻
	59	1	○	•
	8Ø	2	△	•
1.8Ø	3	■	▲	◼
OUT OF RANGE -				



CLIMB	CLIMB
3529	3531
3532	3533
3534 3	3536 3
3537	3538
3122	3124
3127	3130
3133	3136 *
3139	3142
3145 *	3151
3153	3215
3216	3218
3223	3227 *
3247 *	3236
3237	3077
3090	2087
3098	3097
3100 z	3105 z
3108	3109
3111	3112

RDG. 3529

FIGURE 14n

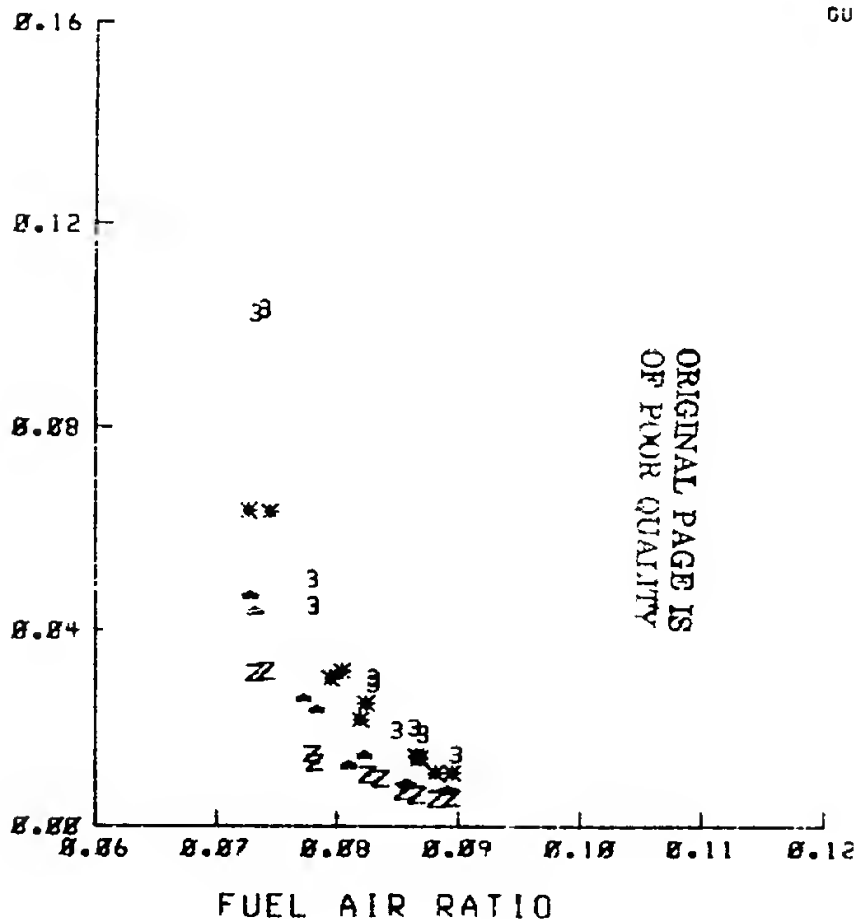
NASA LEAN-OUT DATA

TEMP. 100°F REL. HUM. 0, 30, 60, 80%
APPROACH EMISSIONS Ø-32Ø-DIAD

TEMP. DEG.F	REL. HUMIDITY			
	Ø	3Ø	6Ø	8Ø
5Ø	Ø	Ø	Ø	+
59	1	Ø	•	X
68	2	Δ	•	X
100	3	•	•	Z

CUT OF RANGE -

NOX LBS/MODE



APPROACH
3013
3019
3026 3
3034
3040
3125
3131
3137 *
3143
3149
3211
3219
3226 *
3235
3244
3078
3084
3098 Z
3104
3113

APPROACH
3016
3023
3031 3
3037
3043
3128
3134
3140 *
3146
3152
3214
3222
3231 *
3238
3251
3081
3089
3101 Z
3107
3116

FIGURE 140

GO MODAL EMISSIONS VERSUS FUEL-AIR RATIO

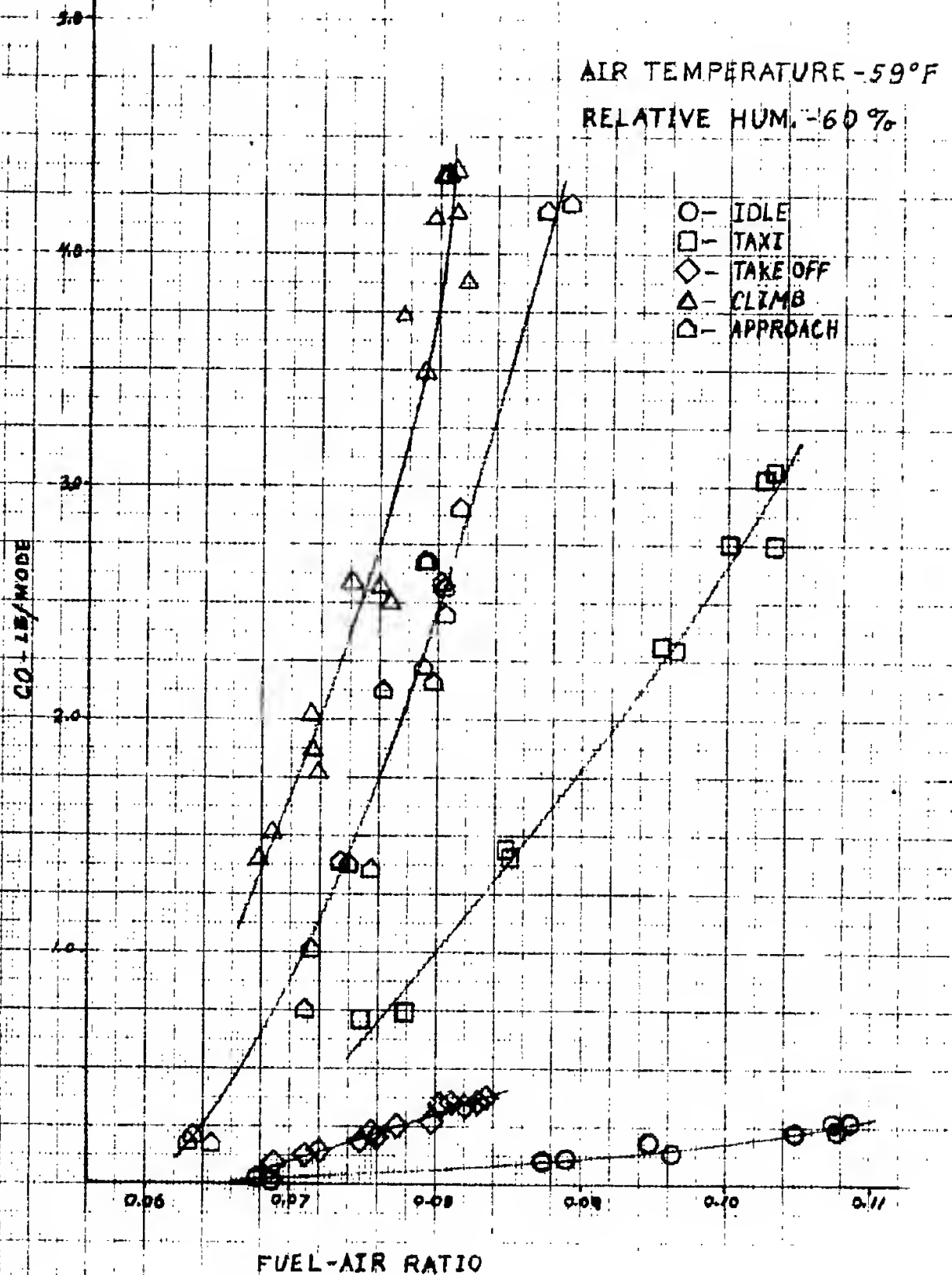


FIGURE 15

HC MODAL EMISSIONS VERSUS FUEL-AIR RATIO

AIR TEMPERATURE - 59 °F

RELATIVE HUM - 60 %

- - IDLE
- - TAXI
- ◇ - TAKEOFF
- △ - CLIMB
- ◻ - APPROACH

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HC 10/MODE

0.06

0.07

0.08

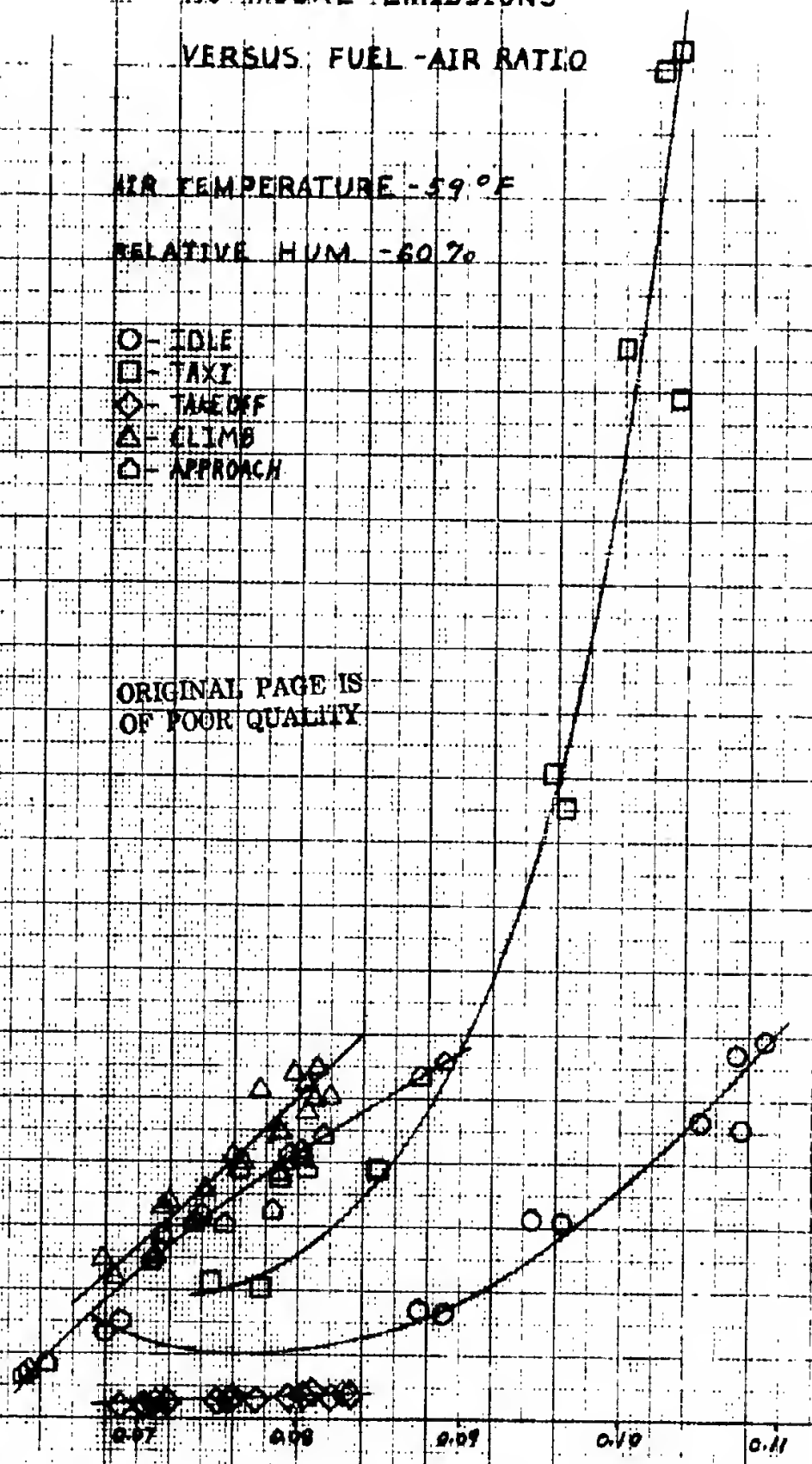
0.09

0.10

0.11

FUEL-AIR RATIO

FIGURE 16



NO_x MODAL EMISSIONS VERSUS FUEL-AIR RATIO

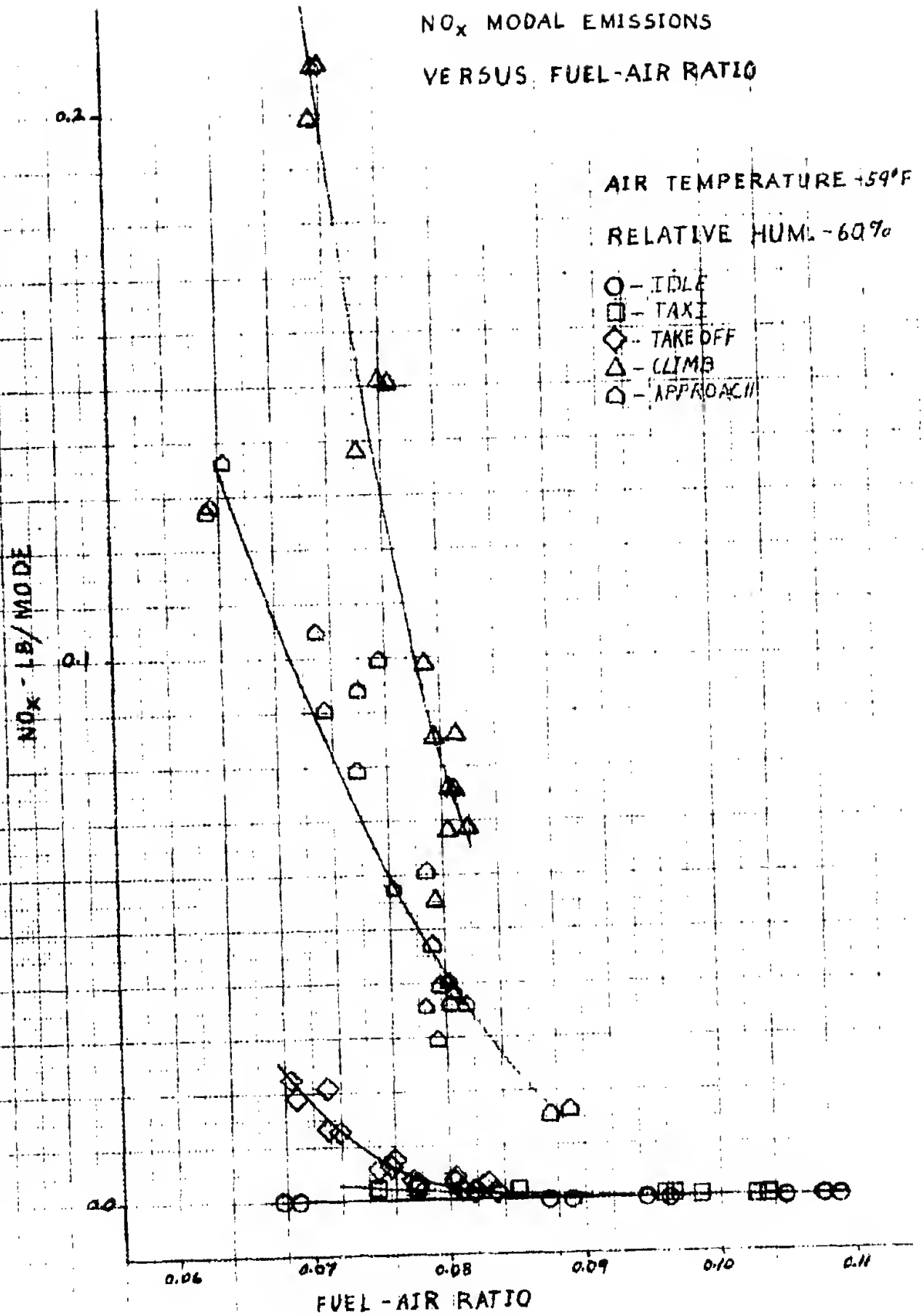


FIGURE 17

COMPARISON OF CYCLE EMISSIONS BASED ON MODAL AND CYCLE DATA

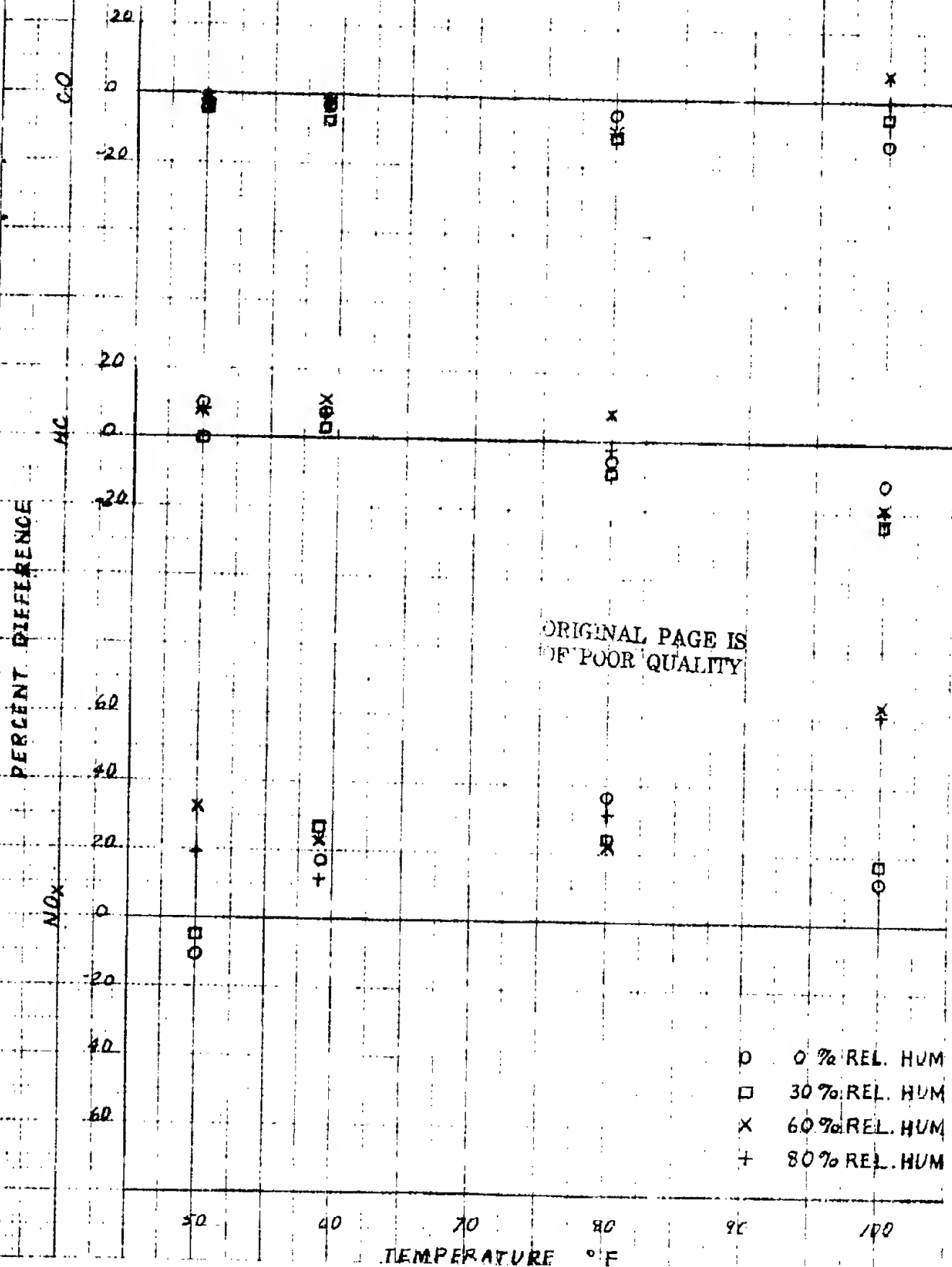


FIG 18

1 Report No NASA TM X-73507, Volume I		2 Government Accession No		3 Recipient's Catalog No	
4 Title and Subtitle EFFECT OF AIR TEMPERATURE AND RELATIVE HUMIDITY AT VARIOUS FUEL-AIR RATIOS ON EXHAUST EMISSIONS ON A PER-MODE BASIS OF AN AVCO LYCOMING O-320 DIAD LIGHT AIRCRAFT ENGINE VOLUME I - RESULTS AND PLOTTED DATA				5 Report Date	
				6 Performing Organization Code	
7 Author(s) Michael Skorobatchkyi, Donald V. Cosgrove, Phillip R. Meng and Erwin E. Kempke, Jr.				8 Performing Organization Report No E-8916-2	
				10 Work Unit No	
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12 Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546				14 Sponsoring Agency Code	
15 Supplementary Notes					
16 Abstract A carbureted four-cylinder air-cooled O-320 DIAD Lycoming aircraft engine was tested to establish the effects of air temperature and humidity at various fuel-air ratios on the exhaust emissions on a per-mode basis. The test conditions included carburetor lean-out at air temperatures of 50 ^o , 59 ^o , 80 ^o , and 100 ^o F at relative humidities of 0, 30, 60, and 80 percent. Temperature-humidity effects at the higher values of air temperature and relative humidity tested indicated that the HC and CO emissions increased significantly, while the NO _x emissions decreased. Even at a fixed fuel-air ratio, the HC emissions increase and the NO _x emissions decrease at the higher values of air temperature and humidity. The report is divided in two volumes: Volume I contains the results and plotted data, and Volume II contains the data taken at each of the individual test points. (The data of Volume II are included on microfilm in a pocket at the back of Volume I.)					
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